Hydrogeology of the Kabul Basin

Part II:

Groundwater geochemistry and microbiology

BGR

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S U M M A R Y

Shallow groundwater is currently the most important drinking water resource for the inhabitants of Kabul. It is pumped up by countless hand-pumped wells throughout the city and accounts for 85 % of the total supply. Because there is no systematic sewage treatment or refuse collection, the shallow groundwater is affected by considerable contamination and the associated hygiene problems. The high mortality rate of infants is probably partially due to the contaminated water.

A groundwater sampling campaign conducted in 2004 throughout the city of Kabul involved the extraction and analysis of around 190 water samples. The aim was to characterise the water quality in detail and was particularly concerned with the contamination of water by anthropogenic pollution. The shallow groundwater generally has a weakly oxidising redox environment with oxygen depletion, probably caused by the sewage. Together with the neutral pH, this prevents the mobilisation of trace metals. Local groundwater salinisation has been identified e.g. in the former swamps to the west of the airport.

Natural processes which have a effect on the quality of the groundwater are:

- Interaction of groundwater with carbonate rocks causing hardening of the water throughout the area: this hardness buffers acidic contaminants, e.g. from the oxidation of sewage, and also gives rise to a high encrustation potential for wells, pipes and household appliances.

- Strong evaporation associated with the mainly negative hydrological balance in the Kabul Basin: evaporating water leaves behind dissolved salts which become concentrated. This raises the salt concentration as well as the concentrations of some problematic constituents, e.g. borates. The recent drought and the import of material, e.g. food and construction materials, considerably worsens this problem.

Considerable anthropogenic immissions are identifiable in the urban area which have a serious impact on the natural groundwater quality, e.g. through massive input of nutrients and bacteria from sewage and uncontrolled waste disposal.

Sewage-related immissions are clearly identifiable compared to the data from the 1960s. The concentrations of nutrients and other salts (nitrate, sulphate, chloride), have increased accordingly. Denitrification consumes large amounts of faecal biomass. The acid input arising from the chemical transformation processes of the sewage are buffered by the dissolved carbonates of the water, but this in turn increases the hardness of the water further.

The aquifers in the Kabul Basin present no barrier to the spread of contaminants because of their sandy to gravely composition and the associated good permeabilities. In contrast, shallow loess beds are invaluable in this respect particularly for the retention of faecal bacteria from the countless cess pits. Protection of the loess beds should be given a high priority.

The information acquired by this study is an important basis for practical recommendations for action and the intended future regulated management of groundwater resources in the Kabul Basin.

A C K N O W L E D G E M E N T

C O N T E N T S

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1. Introduction

Because of the drought that has continued for several years now and the destruction of the infrastructure as a result of the war, the inhabitants of Kabul (whose population has increased considerably in recent years) is largely dependent on groundwater for its drinking water needs. Because barely 15 % of the inhabitants are connected up to the central water supply system, the city contains thousands of shallow hand-pumped wells which supply the drinking water needs of the rest of the inhabitants.

Sewage is largely disposed of in countless domestic drainage pits and open sewage channels along the streets of Kabul. Therefore it is likely that the important shallow groundwater aquifers are probably contaminated by immissions of contaminants. The high infant mortality rate of approx. 15 % is largely attributable to diarrhoea which is itself a result of contaminated water.

As part of the project financed by the Foreign Office of the Federal Republic of Germany - "Improving Groundwater protection and risk assessment of drought problems in the Kabul Basin, Afghanistan" - the Federal Institute for Geosciences and Natural Resources (BGR) has trained its Afghan colleagues in the use of modern hydrogeological methods and worked together with the Afghan colleagues to conduct a joint hydrogeological field data collection campaign. These investigations also included the analysis of the chemical quality of the groundwater. This information is vital to assess the hygienic quality of this important resource.

This report presents the results of a groundwater sampling campaign carried out in the urban area of Kabul in 2004 and its hydrochemical evaluation. The aim of this analysis is the comprehensive characterisation of the water quality including in particular the most important processes and influencing parameters. Special attention was given to drinking water hygiene and the contamination of water by anthropogenic effects. The information acquired in this way is an important source of information for a future management of groundwater resources in the Kabul Basin.

2. Implementation

2.1 Groundwater sampling campaign 2004
The measures carried out as part of the groundwater protection project described above aimed not only at the training of staff at the local Afghan partner institutions, but also the most complete possible evaluation of the groundwater quality in the inhabited part of the Kabul Basin. BGR's local partner organisations included:

1) Ministry of Mines and Industries (**MMI**)
2) Ministry of Irrigation, Water Resources and Environment (**MIWRE**)
3) Kabul University, Faculty of Geosciences (**KU**)
4) Kabul Polytechnic University (**KPU**)

From April to August 2004, BGR and its project partners investigated 290 shallow and deep wells in the city of Kabul and recorded the specific well data and the associated onsite hydrochemical parameters. This information was recorded in the project well database. The parameters recorded onsite during the measuring campaign included:

a) Hydrochemical onsite parameters
Specific electrical conductivity, pH, redox potential, dissolved oxygen, temperature, nitrate concentration, total number of aerobic bacteria, total number of coliform bacteria.

b) Specific well parameters
Location description, GPS co-ordinates, well type and construction type, pump type and service life (if any), static groundwater level in shaft wells (if measurable)

The measurement campaign aimed to cover the whole of the city of Kabul where possible. Unfortunately, some areas in the south and south-east in particular could not be surveyed for security reasons. The outer districts and slum districts in Kabul in particular are risky areas to visit. The local authorities issued a warning of attacks and robberies. Nevertheless, around 85 - 90 % of the whole city was included in the survey. The largely agricultural surroundings of Kabul were not included in this study, also because of security reasons. This region was sampled by USGS experts also in 2004 (BROSHEARS et al. 2005).

Because no well records or lists exist, the districts were visited successively to record the wells. The minimum distance between the surveyed wells should not be less than 500 m. On average, 4 to 7 wells were surveyed on every day of the field work. Figure 2.1 shows the percentage of the total number of wells investigated by each of the teams.

2.2 Surface water sampling campaign 2005
In late July/August 2005, eight surface water samples were taken by BGR personnel and analysed in the BGR lab. The samples were from:

- Paghman river (2 samples, one at the source (spring) and one close to the confluence with Kabul river)
- Logar river (2 samples, at Bagrame, bridge)

- Kabul river (2 samples, one at Artang bridge (Kabul City), one at Camp Warehouse after confluence with Logar river)
- Kharga Lake (reservoir lake near Paghman)
- Karez Amin (a spring at the foot of a collapsed Karez on the eastern flank of the Logar valley, southeast of Momozi)
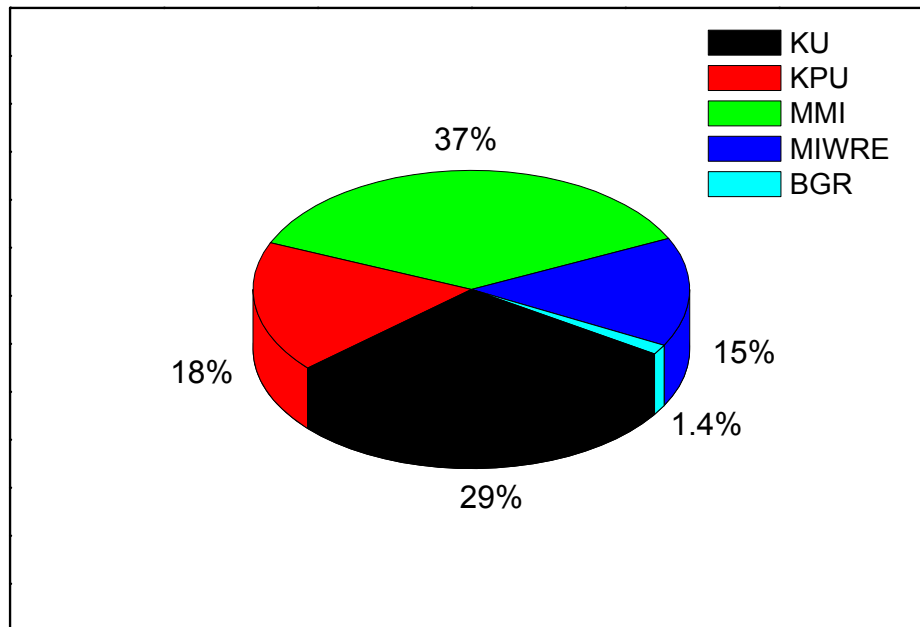
Fig. 2.1: Proportion of investigated wells covered by each of the Afghan partner organisations.

2.3 Chemical analysis

Important hydrochemical parameters of the water samples such as pH, specific electrical conductivity, dissolved oxygen concentration, temperature, and redox potential were analysed during onsite sampling because they may change in samples taken for subsequent analysis (Table 2.1; Fig. 2.2, 2.3). These parameters were also used to determine the best time for sample extraction: water was pumped out until stable values were achieved. Multi-parameter measuring equipment from WTW, type Multi 340 was used for the analysis (Fig. 2.3). These were equipped with appropriate measuring probes (all by WTW):

- pH, temperature: Sentix 41
- redox potential: Sentix ORP
- specific electrical conductivity: TetraCon
- oxygen: CellOx 325

The concentration of the dissolved inorganic carbon species hydrogen carbonate, carbon dioxide and carbonate were determined - where relevant - by onsite titration (Fig. 2.4). Contamination with micro-organisms was determined with the help of semi-quantitative immersion tests (Paddle test) manufactured by HACH. This testing was carried out onsite in Kabul.

Fig. 2.2: Sampling a well in the city of Kabul. The well outflow is connected to the measuring equipment by a rubber hose (photo: TÜNNERMEIER).

Fig. 2.3: Measurement of onsite parameters in pumped water using electrodes in a flowthrough cell (photo: TÜNNERMEIER).

Fig. 2.4: Onsite titration of inorganic carbon species by Afghan colleagues (photo: TÜNNERMEIER).

The analysis of the concentrations of major and trace elements in the water samples could not be carried out locally because of the absence of a suitable water laboratory in Afghanistan. 186 water samples were therefore shipped to Germany and analysed at BGR's hydrochemical laboratory in Hannover (Department B 4.16). This analysis involved the analytical methods listed in table 2.1. Around 65 % of the total number of water samples were analysed in this way.

The results of the onsite and laboratory analyses are summarised in a table in Appendix 10. Values which exceed WHO recommendations (World Health Organisation of the UNO) are highlighted in bold and given a grey background.

The USGS (United States Geological Survey) undertook a similar sampling campaign in parallel to the BGR campaign (BROSHEARS et al. 2004). 148 wells were visited and 108 water samples taken. The parameters investigated corresponded roughly to those looked at by BGR. USGS took much fewer samples in the city of Kabul than BGR but were able to collect some samples from the rural parts of the Kabul Basin which BGR did not visit for security reasons. Because the two data sets complement each other well, the exchange of data was arranged in March 2005.

Table 2.1: Sample treatment and analytical methods (see following page for detailed explanations)

Substance	Method	Sample volume	Testing bottle type	Sample pre-treatment	Filtration
Sulphate	IC	500	HDPE screw bottle	bubble-free filling	none
Chloride	IC	500	HDPE screw bottle	bubble-free filling	none
Fluoride	IC	500	HDPE screw bottle	bubble-free filling	none
Bromide	IC	500	HDPE screw bottle	bubble-free filling	none
Nitrate	IC	500	HDPE screw bottle	$HgCl_2$ poisoning	
Nitrite[1]	Photometer	500	HDPE screw bottle	$HgCl_2$ poisoning	
Silica as SiO_2	ICP-OES	100	HDPE screw bottle	1 ml HNO_3/100 ml sample, conc. Suprapur	0.45 µm cellulose acetate, conditioned with sample
Phosphate[2]	Photometer	100	HDPE screw bottle	none	
Calcium	ICP-OES	100	HDPE screw bottle	1 ml HNO_3/100 ml sample, conc. Suprapur	0.45 µm cellulose acetate, conditioned with sample
Magnesium	ICP-OES	100	HDPE screw bottle	1 ml HNO_3/100 ml sample, conc. Suprapur	0.45 µm cellulose acetate, conditioned with sample
Sodium	ICP-OES	100	HDPE screw bottle	1 ml HNO_3/100 ml sample, conc. Suprapur	0.45 µm cellulose acetate, conditioned with sample
Potassium	ICP-OES	100	HDPE screw bottle	1 ml HNO_3/100 ml sample, conc. Suprapur	0.45 µm cellulose acetate, conditioned with sample
Dissolved iron	ICP-OES	100	HDPE screw bottle	1 ml HNO_3/100 ml sample, conc. Suprapur	0.45 µm cellulose acetate, conditioned with sample
Barium	ICP-OES	100	HDPE screw bottle	1 ml HNO_3/100 ml sample, conc. Suprapur	0.45 µm cellulose acetate, conditioned with sample
Strontium	ICP-OES	100	HDPE screw bottle	1 ml HNO_3/100 ml sample, conc. Suprapur	0.45 µm cellulose acetate, conditioned with sample
Dissolved aluminium	ICP-OES	100	HDPE screw bottle	1 ml HNO_3/100 ml sample, conc. Suprapur	0.45 µm cellulose acetate, conditioned with sample
Dissolved manganese	ICP-OES	100	HDPE screw bottle	1 ml HNO_3/100 ml sample, conc. Suprapur	0.45 µm cellulose acetate, conditioned with sample
Ammonium[2]	Photometer	500	HDPE screw bottle	$HgCl_2$ poisoning	
Alkalinity (ALK43)[4]	Titration HCl	250	Field measurement, titration onsite/field laboratory		
CO_2 acidity (ACY82)[4]	Titration NaOH	250	Field measurement, titration onsite/field laboratory		
Redox potential	Potentiometric		Field measurement	none	
Spec. electr. conductivity	Resistance		Field measurement	none	
Oxygen concentration	Amperometric		Field measurement	none	
pH	Potentiometric		Field measurement	none	
Temperature	Resistance		Field measurement	none	
Aerobic bacteria	visual		Immersion test, incubation 37 °C (36 h)		
Coliform bacteria	visual		Immersion test, incubation 37 °C (36 h)		

Explanations for Table 2.1

IC = The anions F^-, Cl^-, Br^-, NO_3^-, SO_4^{2-} were analysed with ion chromatography analogous to DIN EN ISO 10304-1 (1995). Conductivity detection with a membrane suppresser technique is used (eluent: KOH; regenerant solution: H_2SO_4).

ICP-OES = The concentration of the main elements, Na, K, Ca, Mg, B, Al, Si, Mn and Fe were analysed using ICP-OES (inductive coupled plasma atom emission spectrometry) analogous to DIN EN ISO 11885 (1998).

[1] = nitrite analysed by photometer in accordance with DIN 26777 (1993)

[2] = phosphate analysed by photometer in accordance with DIN EN 1189 (1996)

[3] = ammonium analysed photometer in accordance with DIN 38406 (1983)

[4] = The alkalinity or acid capacity of the water samples was determined from a 100 ml aliquot by titration with 0.1 n HCl to an end point of pH = 4.3 (DIN 38409). The end point is determined using a pH measuring apparatus (WTW-Multi 340i) with a glass electrode (WTW SenTix 41). The CO_2 acidity (base capacity) is determined analogously from a 100 ml aliquot by titration with 0.1 n NaOH to an endpoint of pH = 8.2. The end point is determined by a pH measuring apparatus (WTW-Multi 340i) with a glass electrode (WTW SenTix 41).

The trace element concentrations of As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Pt, Sb, Sn, Ti and Zn were analysed with ICP-MS (inductive coupled plasma mass spectrometry). The elements Mo, Cd, Sn, Sb, Pt, Hg, Tl and Pb are analysed at low mass resolution (m/Dm = 350), the elements Cr, Co, Ni, Cu and Zn were analysed at medium mass resolutions (m/Dm =3800), and the element As was analysed at high mass resolution (m/Dm = 7500). The element Rh was used as internal standard for all elements.

3. Interpretation of the parameters

3.1 Temperature

The temperature of shallow groundwater is normally dependent on timing and temperature of groundwater recharge and the soil temperature. As already discussed in Part I of this report, recharge in the Kabul Basin primarily involves infiltration from the rivers and at the basin rims. Because the highest river discharges occur in April/May shortly after the snow melts, this is probably the most likely period for recharge. The average temperature of the groundwater is around 16 °C (Fig. 3.1, 3.2) and is therefore much higher than the annual average temperature, as well as being higher than the temperature at the main discharge times. One must therefore assume an additional heat source which is probably associated with the percolation of warmed-up effluent (household cleaning water, drainage pits) and to a lesser extent also the heat radiated by heating systems of houses. These processes generate local temperatures of up to approx. 20 °C. However, it should also be noted that the sampling mainly took place during the summer which may have had an influence on the temperature.
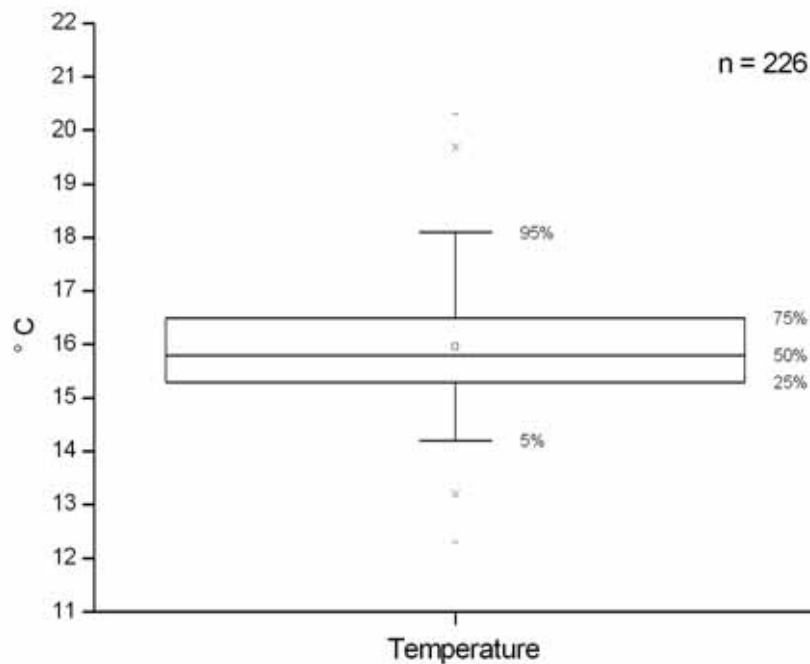
Fig. 3.1: Box-Whisker diagram of groundwater temperatures in the Kabul Basin 2004.

However, the spatial distribution of groundwater temperatures does not reflect the sources of heating postulated above (Appendix 1). The spatial distribution reveals that the highest temperatures are present in the less built-up north-western edge of the basin. Reasons for this are yet unresolved.
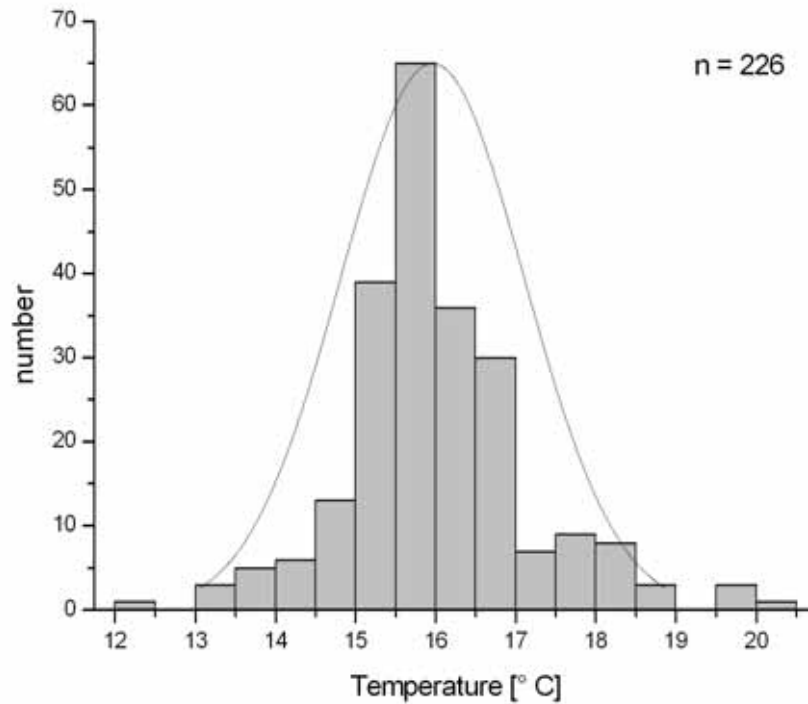
Fig. 3.2: Histogram of groundwater temperatures in the Kabul Basin 2004.

3.2 Specific electrical conductivity

The specific electrical conductivity (EC = electrical conductivity) is a sum parameter which approximately describes the salt concentration in the water. Because saline water can only be used in a restricted way for human consumption and the irrigation of agricultural areas and gardens, conductivity is a very useful parameter. It is also very easy to measure. Typical specific electrical conductivities S_s at 25 °C are:

	µS/cm
Water, pure	0.042
Distilled water	$0.5 < S_s < 3$
Rain water	$5 < S_s < 100$
Groundwater, fresh	$50 < S_s < 2000$
Sea water	$45000 < S_s < 55000$
Brine	> 100000

Our analysis revealed that a large number of samples (40 %) exceeded the limit of 1500 µS/cm recommended by WHO - in other words, have salt concentrations which are too high for human consumption, at least in the long turn (Fig. 3.3). 12 % of the samples would still even fail the European drinking water limit of 2500 µS/cm. Because of the acute water shortage in Afghanistan, conductivities of up to 3000 µS/cm are tolerated for human consumption.

Reasons for the elevated conductivities could include:

- Percolation of sewage with high salt concentrations from drainage pits, road ditches etc. into the shallow groundwater
- Incineration of domestic refuse in road ditches
- relative enrichment of salts during groundwater recharge (or use) as a result of strong evaporation
- (anthropogenic) immissions via infiltration from the Kabul and Logar rivers
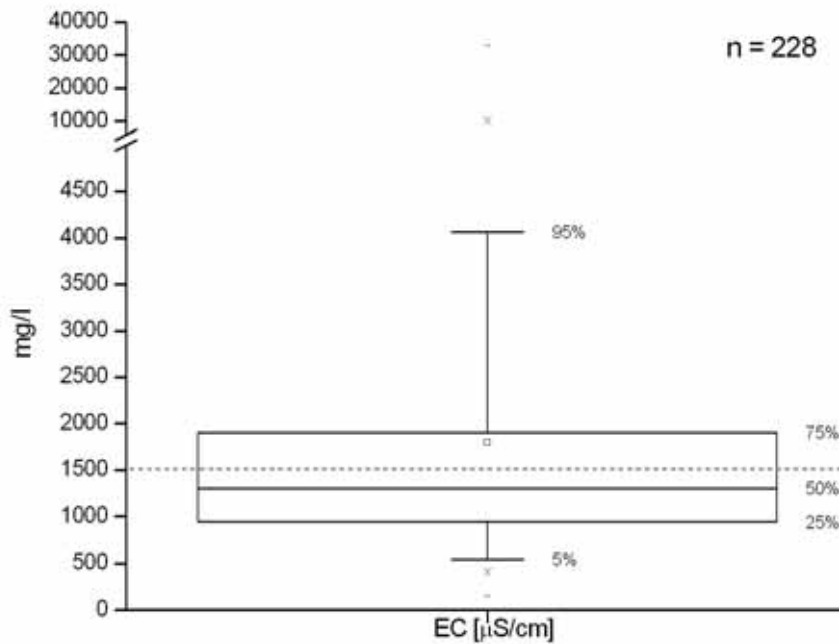
Fig. 3.3: Box-Whisker diagram of specific electrical conductivity (EC) of groundwater in the Kabul Basin 2004.

Analysis of the correlation between specific electrical conductivity and important dissolved constituents in the groundwater revealed a clear association with sodium, chloride and sulphate irons (Fig. 3.4). The quality of higher mineralised waters in particular is mainly influenced by these irons. Calcium, representing the hardness (→ 3.3.2, 3.3.3) showed a much weaker correlation (Fig. 3.4).
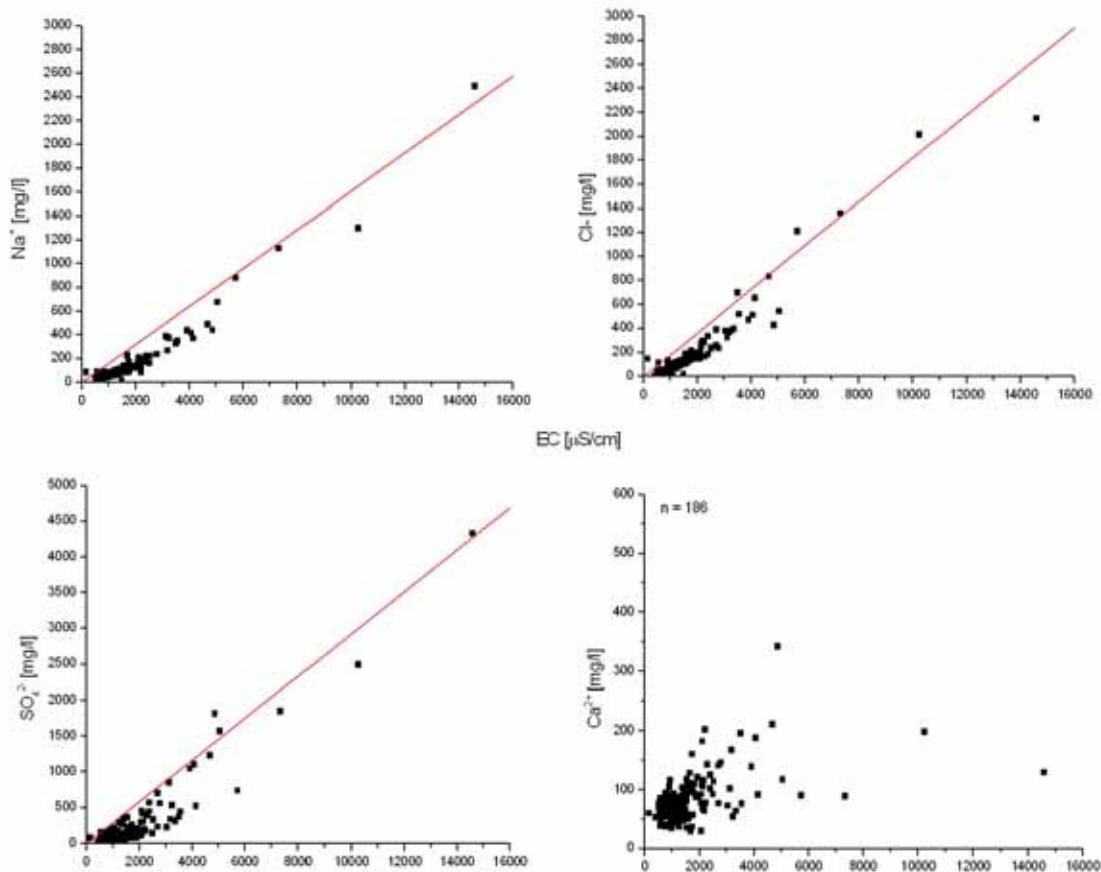
Fig. 3.4: Correlation between specific electrical conductivity (EC) and sodium, chloride, sulphate and calcium in groundwater in the Kabul Basin 2004.

Zones with clusters of higher values with respect to the spatial distribution of specific electrical conductivity were recognised, e.g. in the densely populated northern part of the city (Appendix 2). This is probably attributable to the impact of the city and its sewage. By contrast, the less densely populated southern part of the city (Darulaman) is less affected.

Particularly high values were found to the west of the airport (north of the Wazirabad district). This is associated with local swamps which existed until the end of the 1970s but are currently dry. The salt concentrations within this area are probably caused by the evaporation of surface water or the rise of shallow groundwater by capillary action. Another natural salination zone in the eastern part of the basin had already been identified in earlier investigations (BÖCKH 1971). This is located close to the confluence of the Logar and Kabul rivers.

3.3 pH and pH-dependent reactions

3.3.1 pH

pH, which is defined as the negative decimal logarithm of the hydronium ion activity (H^+) is a very important control parameter for numerous hydrochemical reactions, and is also very important for assessing the usability of the water in technical systems. Many important hydrochemical processes are dependent on pH, e.g.:

- carbonate equilibrium ($\rightarrow$ 3.3.2)
- the solubility of numerous minerals (e.g. calcium, magnesium, iron, manganese and aluminium minerals)
- surface charge of numerous minerals and thus their sorption capacity

As a generalisation, the pH of the groundwater in the Kabul Basin lies in the very weak basic zone in more than 95 % of cases, i.e. very close to neutral (Fig. 3.5). This indicates a well-buffered system ($\rightarrow$ 3.3.2, 3.3.3). This is a very positive quality with respect to the mobilisation of heavy metals from the soil, and the corrosivity of the water ($\rightarrow$ 3.3; 4.4). None of the samples exceeded the recommended limits. The distribution is very homogeneous (Fig. 3.6).
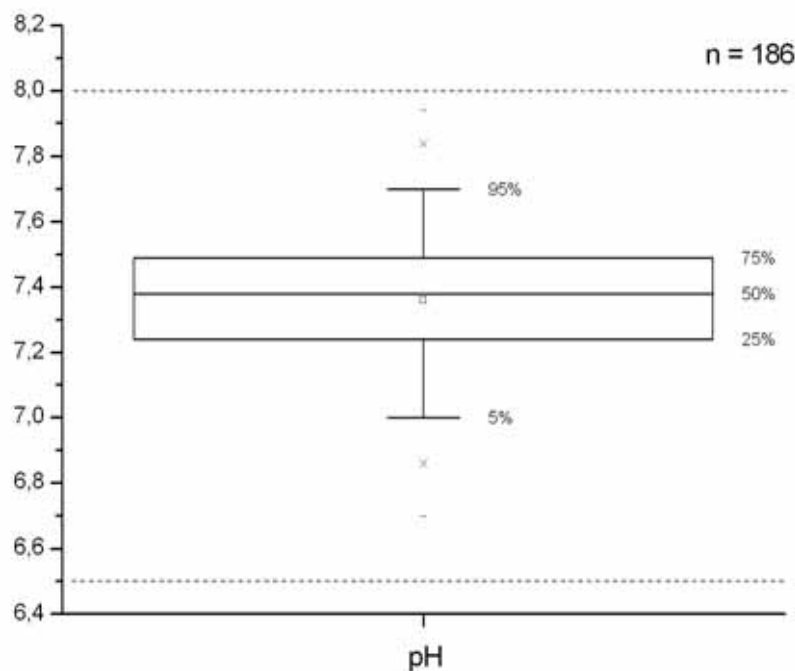
Fig. 3.5: Box-Whisker diagram of groundwater pH in the Kabul Basin 2004.

The spatial distribution of pH in the urban areas shows that the highest values lie at the north-western basin margin (Appendix 3). This could indicate the presence of strong acid immissions in the densely populated city centre which have an impact despite the good buffering properties. The natural pH of the groundwater dominates at the basin edges because of the infiltration of unpolluted waters during groundwater recharge there.
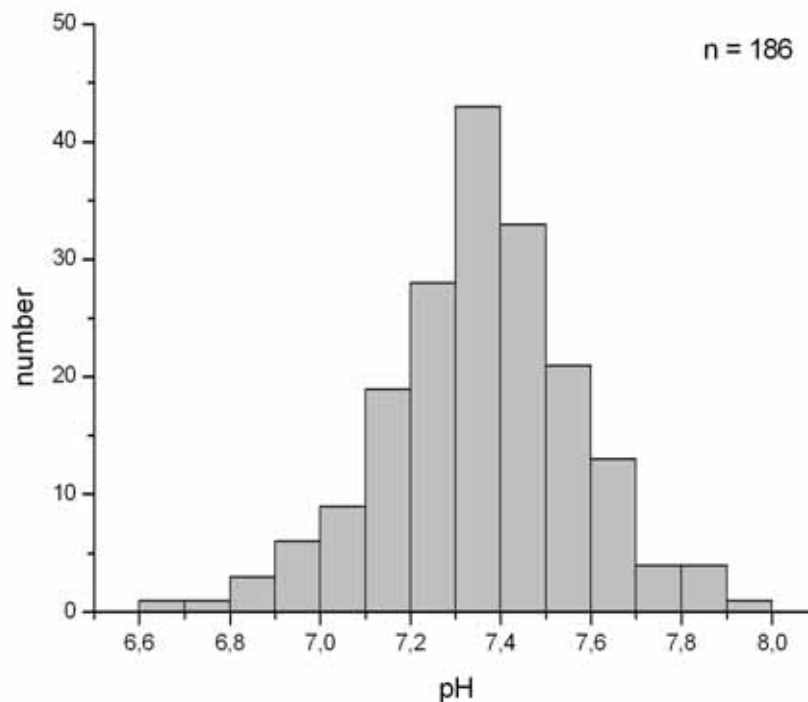
Fig. 3.6: Histogram of groundwater pH in the Kabul Basin 2004.

3.3.2 Carbonate equilibrium

The carbonate equilibrium is of major importance for the quality of many groundwaters because the carbonate minerals calcite ($CaCO_3$), aragonite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) are frequent constituents of the matrix of natural aquifers. The main constituents in water associated with this system are therefore the ions calcium (Ca^{2+}), magnesium (Mg^{2+}), hydrogen carbonate (HCO_3^-), carbonate (CO_3^{2-}) and dissolved carbon dioxide (CO_2).

The solubility of carbonate minerals is strongly affected by the carbon dioxide dissolved in water (CO_2). In the form of the gas carbon dioxide, carbonic acid is present in the atmosphere as well as in soil gas from where it enters the water. The main immission paths are:

- the rotting (mineralisation) of organic matter
- exhalation by (basic) volcanism
- incineration of fossil fuels (coal, peat, wood, oil, gas)

On the other hand, carbonic acid can be fixed by:

- precipitation of carbonates (aragonite, calcite, dolomite etc.)
- photosynthetic production of biomass.

Measured concentrations of calcium, magnesium and hydrogen carbonate in the Kabul Basin already reveal that the interaction of the groundwater with carbonate minerals must play a key role in its quality (Fig. 3.7; 3.10). Carbonate rocks are known from the area surrounding the basin (Malm limestones) and from the base of the basin (Pliocene limestones and marls of the Kabul series) (FESEFELDT in: WIRTZ et al. (1964); see also Part I of this study).

The values recorded here do not affect drinking water hygiene. Although both elements are essential for human life, the amounts required are primarily covered by solid food. High concentrations of magnesium sulphate have a laxative effect.
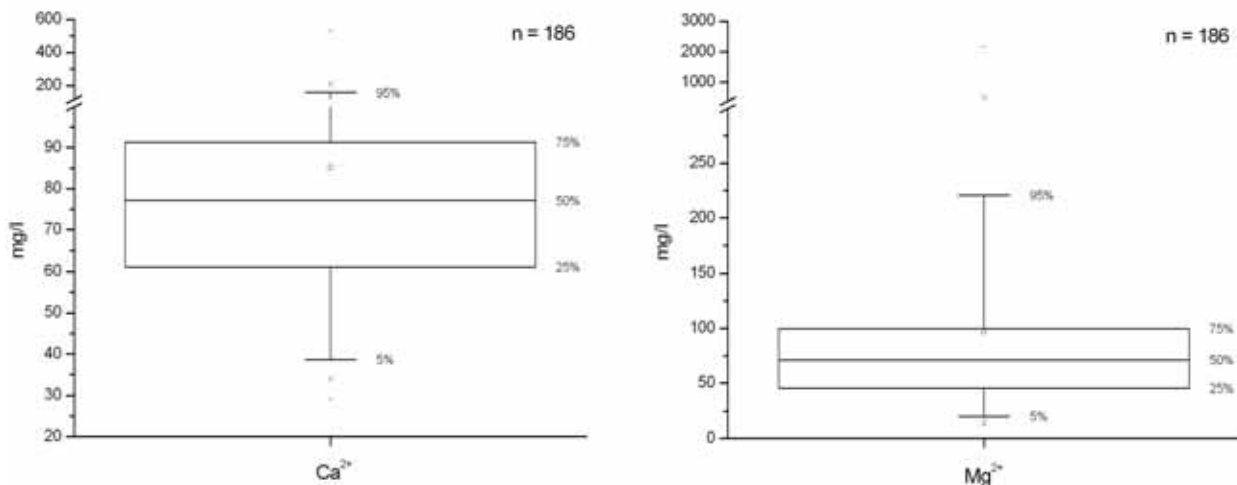
Fig. 3.7: Box-Whisker diagram of calcium and magnesium concentrations in the groundwater in the Kabul Basin 2004.

Waters in contact with limestone typically have molar Ca/Mg ratios of approx. 2.0 : 1 to 1.5:1 (MANDEL & SHIFTAN 1981). Water in contact with dolomite (CaMg(CO$_3$)$_2$) ideally has a ratio of approx. 1 : 1. However, the ratios in reality are usually around 1.4 : 1 to 1.1 : 1 (MANDEL & SHIFTAN 1981).

Remarkably, the magnesium concentrations in the Kabul Basin samples are relatively high compared to the calcium concentrations (Fig. 3.7, 3.8). Approx. 75 % of all samples have lower values than that described above for a dolomite system, i.e. there is a magnesium excess, the median figure for Ca/Mg lies at approx. 0.7 : 1. The USGS investigations revealed a similar picture (BROSHEARS et al. 2005). This indicates that there must be another source of magnesium - or a sink for calcium. A source of magnesium could be the metamorphic Precambrian rocks surrounding the northern and western basin margins, as well as the Palaeozoic phyllites in the south and east. Magnesium-rich metamorphic minerals include for example serpentine (Mg$_6$[(OH)^8/Si$_4$O$_{10}$]), talc (Mg$_3$[(OH)$_2$/Si$_4$O$_{10}$]), cordierite, garnet, chlorite and montmorillonite. The presence of such minerals can give rise to high magnesium concentrations in groundwater (e.g. HEM 1986). A relative enrichment of calcium as a result of ion exchange is thought to be unlikely given the postulated dimensions and the similar sorption affinity of magnesium. Waters which have flown through dolomite and are saturated in this mineral can cause the precipitation of calcite for kinetic reasons. This removes calcium and gives rise to the relative enrichment of magnesium. Such processes have been observed by e.g. HEM (1986), STUMM & MORGAN (1996) and SCHWARTZ & PLOETHNER (2000).
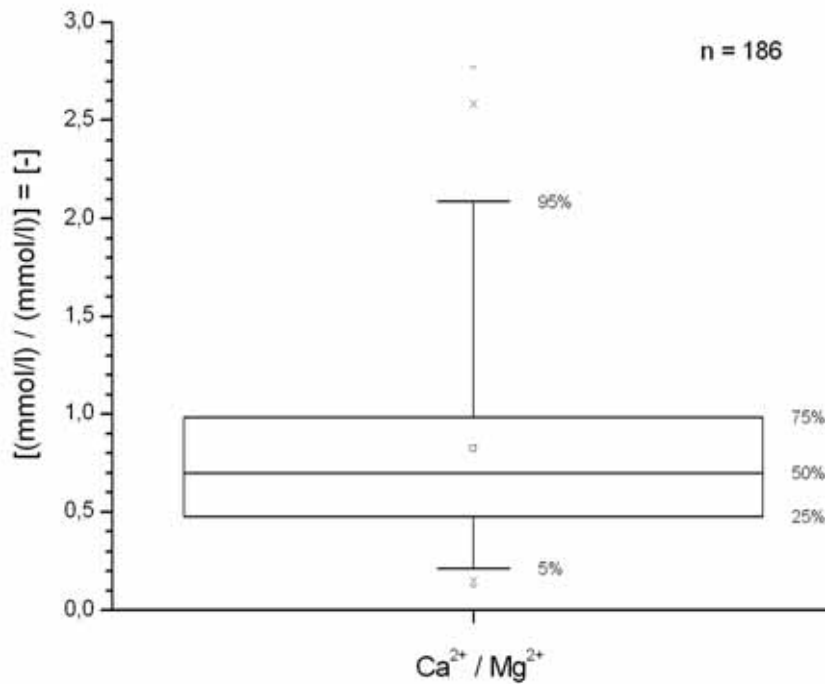
Fig. 3.8: Box-Whisker diagram of the molar calcium/magnesium ratio of Kabul Basin groundwater 2004.

3.3.3 Hardness and carbonate saturation

The properties of "water hardness" are related to the carbonate equilibrium. The precipitation of carbonates ("boiler scale") from oversaturated waters causes major economic damage to pipes, extraction and treatment plants and domestic appliances. Aggressive carbonic acid from carbonate-undersaturated waters can lead to the corrosion of cemented and metallic materials. The hardness also affects the taste of drinks and the consumption of detergents and soap. Total hardness measured at the German hardness scale (° dH) is calculated in equation (R 3.1) from the proportion of main hardness builders calcium and magnesium.

$$GH \; [°dGH] = (CaO + 1.4*MgO)/10 \quad [mg/l] \tag{R 3.1}$$

These values can be divided up into five classes of hardness according to KLUT-OLZEWSKI (LANGGUTH & VOIGT 2004).

Table 3.1: Hardness classes of water after KLUT-OLZEWSKI.

Class	Degree of hardness d°	mmol(eq)/ Ca^{2+} hardness equivalent
very soft	0 < °d < 4	0 - 1.43
soft	4 < °d < 8	1.43 - 2.86
medium hard	8 < °d < 12	2.86 - 4.28
somewhat hard	12 < °d < 18	4.28 - 6.42
hard	18 < °d < 30	6.42 - 10.72

Fig. 3.9 shows the distribution of total hardness in the Kabul Basin samples. More than 80 % of the samples are classified as "hard" or "very hard". This significant hardness gives the water a very high buffer capacity against acid immissions, which is useful for instance to buffer the formation of acid from the nitrification of ammonium ($\rightarrow$ 3.4.3). From a technical point of view, hardness is very undesirable for the aforementioned reasons. This needs to be taken into consideration particularly when considering the construction of a central water supply system.

The significant hardness is of course associated with high carbonate hardness and hydrogen carbonate concentrations (Fig. 3.10). This may be sourced from the dissolution of carbonate minerals or from the mineralisation of biomass (simplified "CH_2O"), e.g. from sewage according to reaction (R 3.2).

$$\text{"CH}_2\text{O"} + O_2 \leftrightarrow HCO_3^- + H^+ \qquad \text{(R. 3.2)}$$
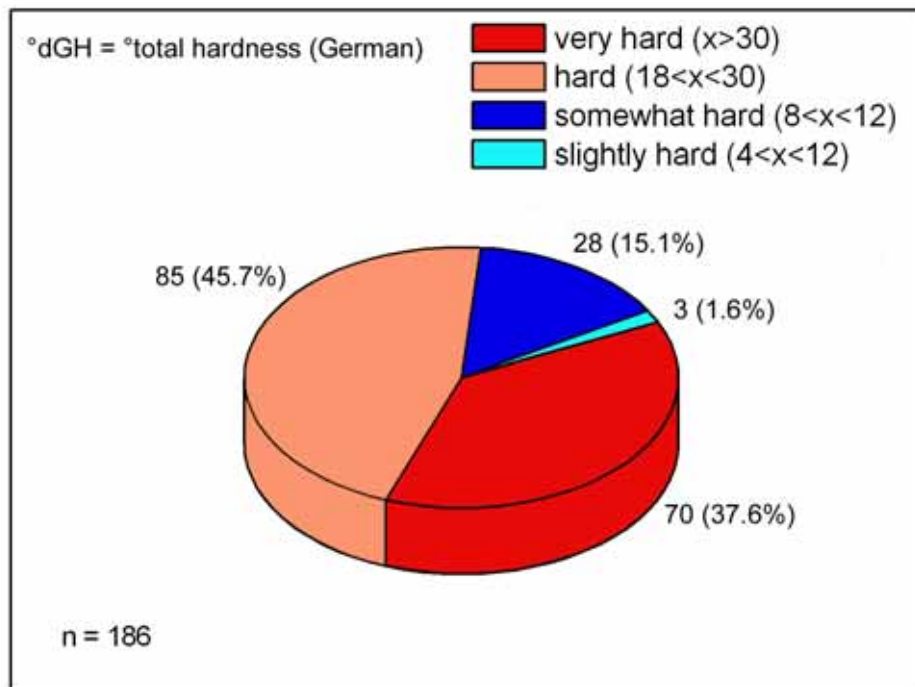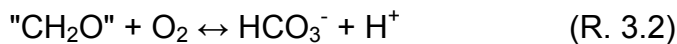
Fig. 3.9: Distribution of total hardness (°dGH) of the Kabul Basin groundwaters 2004 in per cent.

The spatial distribution of hydrogen carbonate concentrations in the Kabul Basin corresponds well with the effect of the mineralisation of biomass from sewage (Appendix 4). The areas with housing and the inner-urban areas in particular have the highest carbonate hardnesses. Much lower values are recorded in the more sparsely populated north-western edge of the basin.
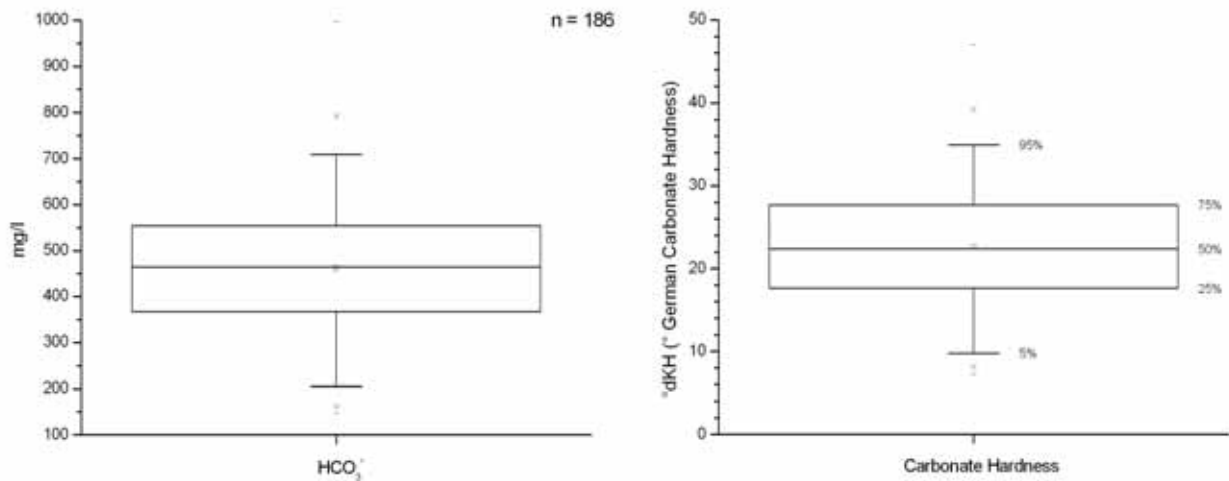
Fig. 3.10: Box-Whisker diagram of hydrogen carbonate concentrations and the associated calculated carbonate hardness of the groundwater in the Kabul Basin 2004.

The dissolution of carbonates must give rise to molar charge equivalents between the cations (earth alkali ions) and the anions ((hydrogen) carbonate). This is not given for calcium but applies to a large number of samples for the total calcium and magnesium concentrations (Fig. 3.11). Additional processes must be involved for the samples with "excess" alkaline earth cations lying to the right of the 1:1 line which require the presence of additional anions. A possible cause could be the dissolution of gypsum or anhydrite (→ 3.4.5).
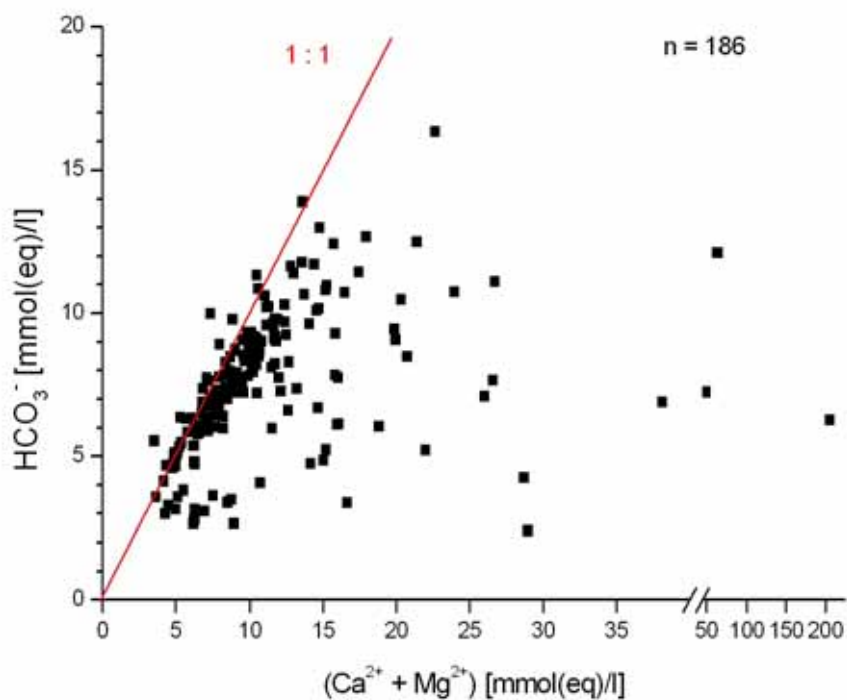
Fig. 3.11: Correlation between calcium and magnesium concentrations and the hydrogen carbonate content of Kabul Basin groundwater 2004.

The saturation state of the water expressed by the saturation index SI, with respect to calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) is a very important parameter for technical applications. It is essential to determine whether the water contains more or less dissolved carbonate than required for equilibrium. The water is either carbonate-oversaturated ($Si > 0$) and therefore can give rise to encrustation, or it is carbonate-undersaturated ($Si < 0$) in which case it contains aggressive carbonic acid and is therefore corrosive and not only dissolves carbonate but also attacks metals.
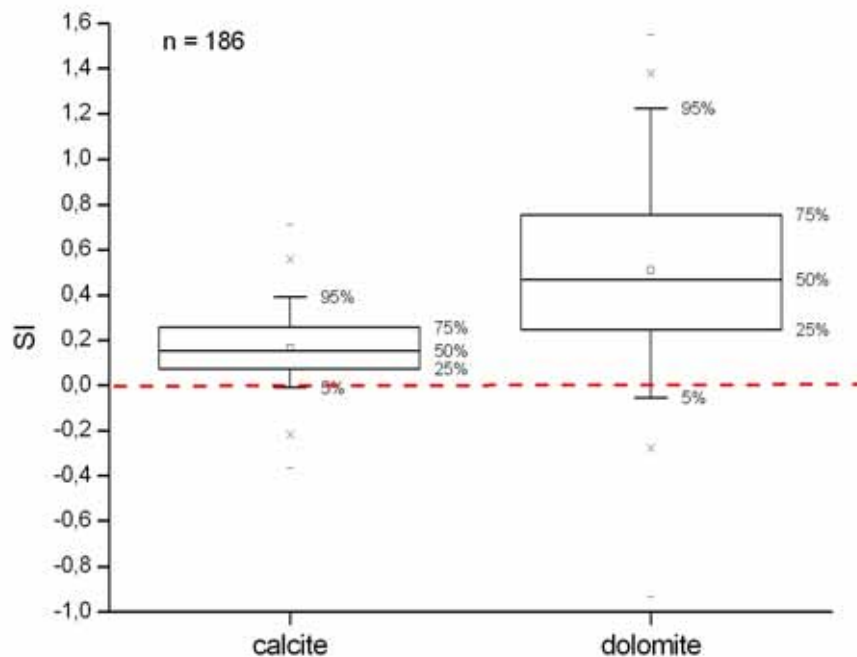
Fig. 3.12: Box-Whisker diagram of the saturation index (SI) for calcite and dolomite of groundwater in the Kabul Basin 2004
$SI > 0$: water oversaturated, mineral phase can precipitate; $SI < 0$: water undersaturated, mineral phase can dissolve.

A notable feature is that the waters are almost always at the saturation point or slightly oversaturated (Fig. 3.12). This is a consequence of the equilibrium with carbonate minerals which clearly must be present in large quantities in the aquifer matrix. The positive indices reveal that the water is non-corroding but able to precipitate carbonates, i.e. encrusting.

The oversaturation of the Kabul Basin groundwater with respect to calcite and dolomite explains the presence of conglomerates at the base of the gravely aquifer. Tests with dilute hydrochloric acid on conglomerate samples supplied by the Faculty of Geosciences, Kabul University, resulted in a strong and immediate reaction (fizzing) and thus showed that the cement of the conglomerate indeed consists of calcite. Over a long period of time, the oversaturation leads to a reduction in pore space and lowers the productivity of the aquifer.

3.4 Redox potential and redox-dependent reactions

3.4.1 Redox potential

The redox potential can be used to infer the redox state of the water, i.e. whether the water is oxidising or reducing. A large number of chemical reactions and technical properties of the water are dependent on this state. Because of the technical conditions involved in the measurement, and the fact that the measured potential is actually a mixed potential of various redox reactions taking place in parallel in the water, the measured values can only be used as a rough guide.

Values measured in the Kabul Basin in 2004 reveal a balanced distribution around an average value of approx. 535 mV (Fig. 3.13, 3.14). The samples therefore lie in the weakly oxidising or oxygen and nitrate depleting zone (Fig. 3.15). In this zone ammonium can be oxidised to nitrate. Reduction of manganese oxides is possible whilst the reduction of iron oxides and sulphates to dissolved iron and respectively sulphide is excluded.
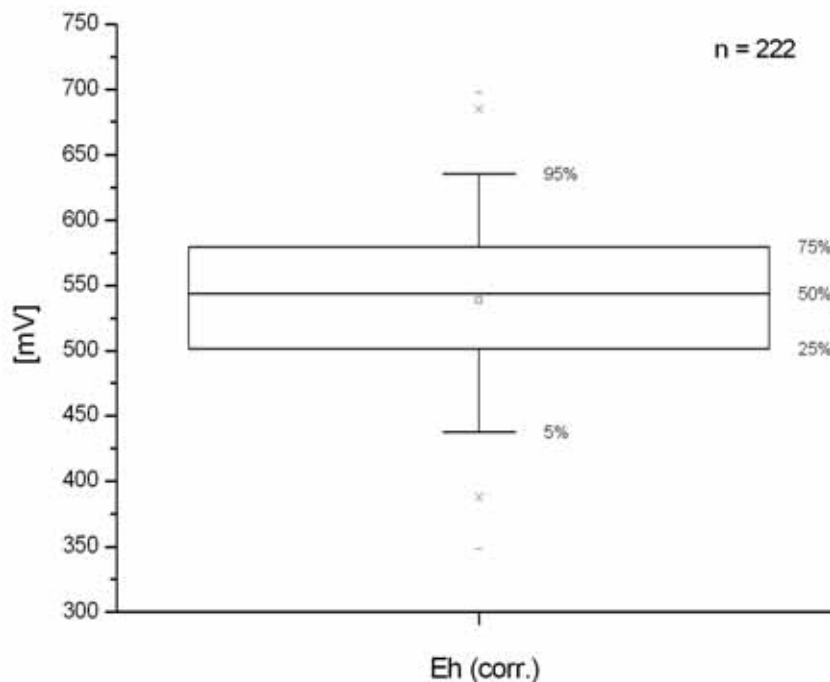
Fig. 3.13: Box-Whisker diagram of Eh (redox potential) of Kabul Basin groundwater 2004.

The spatial distribution of redox potentials shows that the highest, i.e. most oxidic values occur in the southern part of the basin (Darulaman) and the basin edge in the northern sub-basin (Appendix 5). The lower potentials in the city centre could be due to oxygen depleting by anthropogenic immissions, e.g. from sewage.
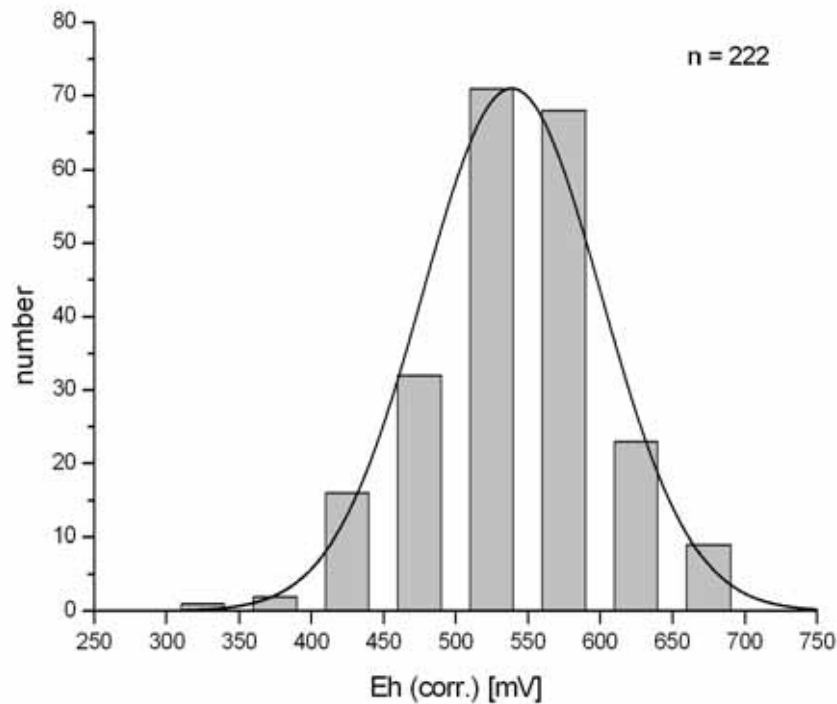
Fig. 3.14: Eh histogram (redox potential) of groundwater in the Kabul Basin 2004
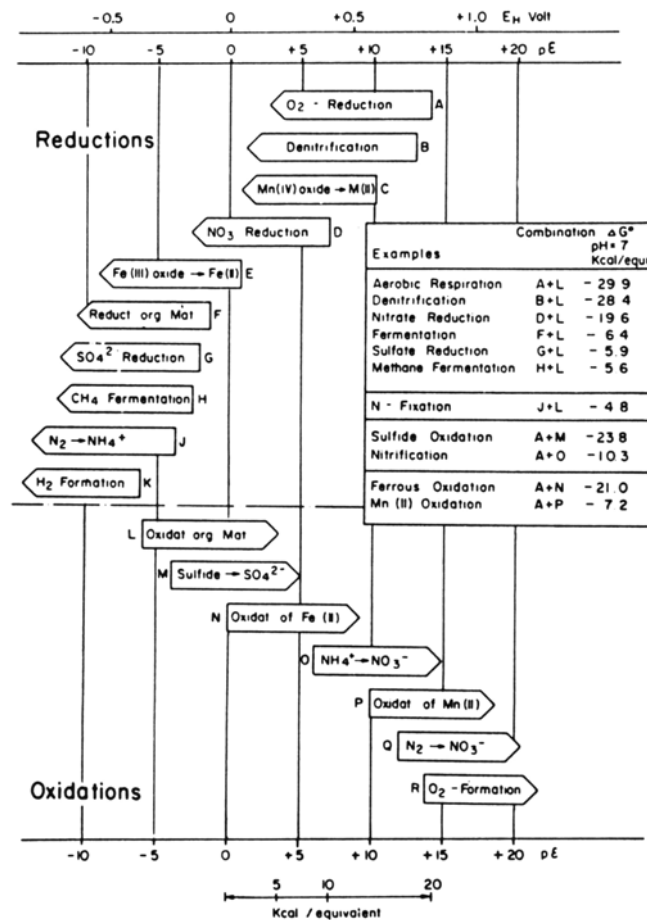
Fig. 3.15: Redox zones in natural systems (STUMM & MORGAN 1981)

3.4.2 Oxygen concentration and saturation

Oxygen enters groundwater in dissolved form as a result of exchange with the atmosphere or soil gas. As a result, the highest concentrations usually occur in the upper parts of the groundwater column. Oxygen is the strongest naturally occurring oxidant in groundwater. It is therefore the first to be consumed during the (microbial) decomposition of organic immissions (e.g. sewage) in accordance with reaction (R 3.3).

$$CH_2O + O_2 \leftrightarrow CO_2 + H_2O \qquad\qquad (R\ 3.3)$$

As already indicated by the redox measurements, the samples lie in the weakly oxidising zone. As a result, concentrations of dissolved oxygen are on average in the low mg/l range (Fig. 3.16).
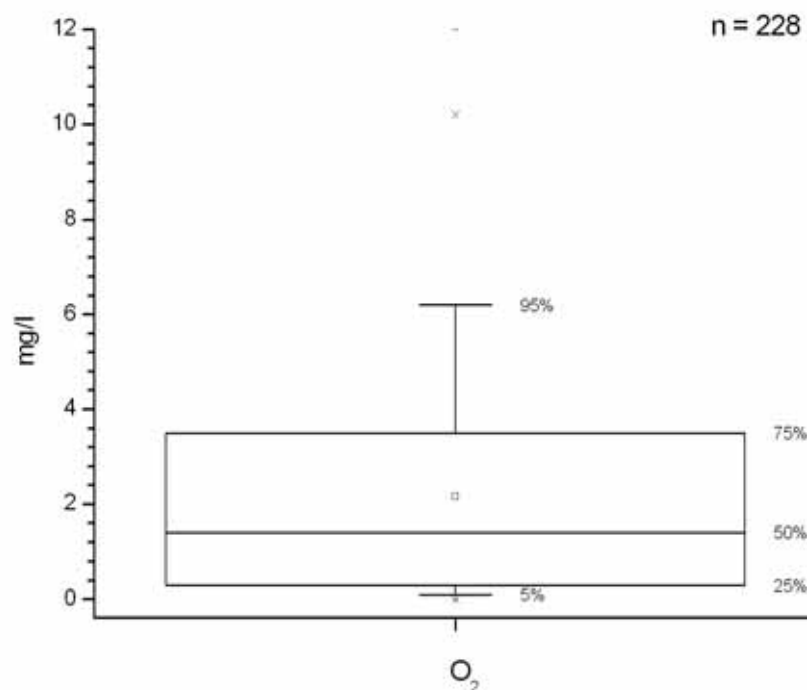
Fig. 3.16: Box-Whisker diagram of dissolved oxygen concentration in groundwater in the Kabul Basin 2004

The temperature-dependent saturation state of the groundwater for oxygen was calculated from the measured concentrations (Fig. 3.17). Although the samples collected from the sampled wells must generally have come from shallow groundwater, less than 25 % of all of the samples have oxygen saturations above 50 %. The medium value is actually less than 20 %. This strongly indicates the presence of oxygen depleting processes which are already taking place in the shallow groundwater.
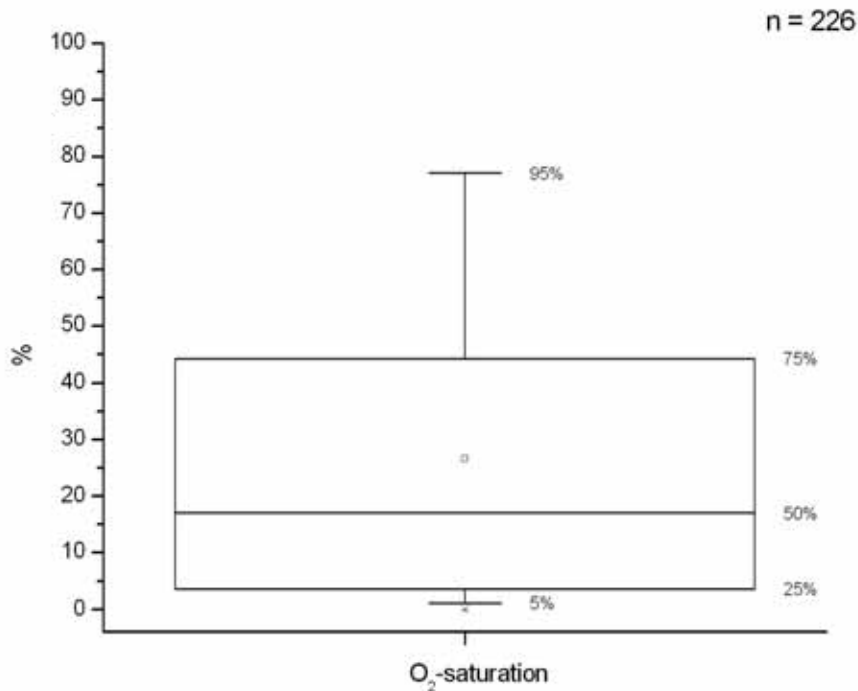
Fig. 3.17: Box-Whisker diagram of relative oxygen saturation of the groundwater in the Kabul Basin 2004

3.4.3 Nitrogen species: nitrate, nitrite and ammonium
The nitrogen species nitrate, nitrite and ammonium are very significant for the overall assessment of drinking water hygiene. The distribution of each of the species is also a good indicator of the redox environment of the groundwater (Fig. 3.15). Nitrate reveals oxic conditions whilst ammonium reveals reducing conditions. Nitrite is a by-product generated at the start of nitrate reduction.

Nitrogen is an essential nutrient for fauna and flora. Whereas the over-fertilisation of soils in Europe has given rise to the strong nitrate contamination of groundwater in many parts, the source of nitrogen in the Kabul Basin is found in the sewage. Nitrogen in sewage is largely in the form of ammonium. However, this oxidises rapidly to nitrate in the presence of oxygen. The ammonium concentrations measured as part of this study were so low (Fig. 3.18) that they barely had any impact on drinking water hygiene: approx. 45 % of the samples were even below the detectable limit of 0.01 mg/l.

However, most of the samples had considerable nitrate concentrations (Fig. 3.19). The ammonium from the sewage must therefore have been converted to nitrate in the pit latrines, the soil or in the shallow groundwater in accordance with reaction (R 3.4). The measured redox potentials support the probability of this reaction (→ 3.4.1).

$$NH_4^+ + 2\ O_2 \leftrightarrow NO_3^- + 2\ H^+ + H_2O \qquad\qquad (R\ 3.4)$$
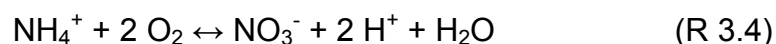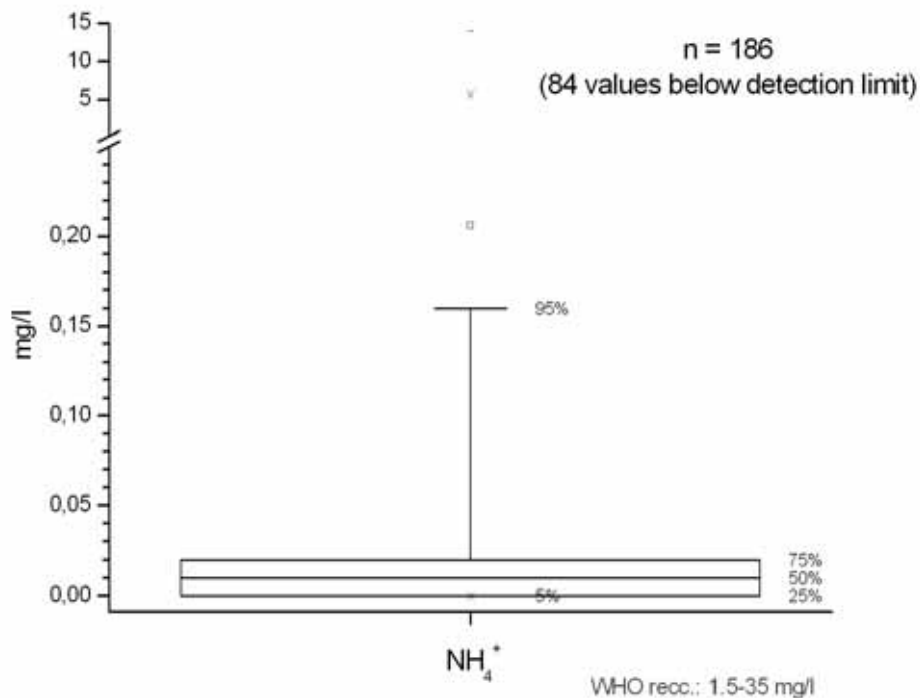
Fig. 3.18: Box-Whisker diagram of ammonium concentration in groundwater in the Kabul Basin 2004. Values below detection limit not shown.

The oxygen required for this reaction must have come from the soil gas or from dissolved oxygen in the shallow groundwater. This explains why the groundwater sampled in the Kabul Basin shows clear signs of oxygen depletion despite its near surface position (→ 3.4.1, 3.4.2). The acid generated by the break-down of ammonium has almost no effect on the pH because of the considerable buffer capacity of the groundwater (→ 3.3.2, 3.3.3).

Nitrate is a very important drinking water hygiene parameter because concentrations above the limit of 50 mg/l can lead to the formation of toxic nitrosamines via nitrite. This represents a considerable risk particularly to small children. Nitrate is reduced by bacteria in the stomach to nitrite which can irreversibly displace the oxygen bound to red blood cells in small children and infants. The children therefore suffer from a lack of oxygen and can even suffocate in extreme cases ("blue baby disease", haemaglobulinanaemia).

Because 42 % of the samples exceed the limit, considerably in some cases (Fig. 3.19, 3.20, 3.21) it is possible that nitrate (alongside the microbial contamination) is one of the causes of the high infant mortality rate which is currently approx. 15 %. Wells with excessive nitrate concentrations should no longer be used to supply drinking water. In 1996, 32.5 % of all hand-pumped wells already exceeded a nitrate concentration of 45 mg/l (TIMMINS: in BANKS & SOLDAL 2002).
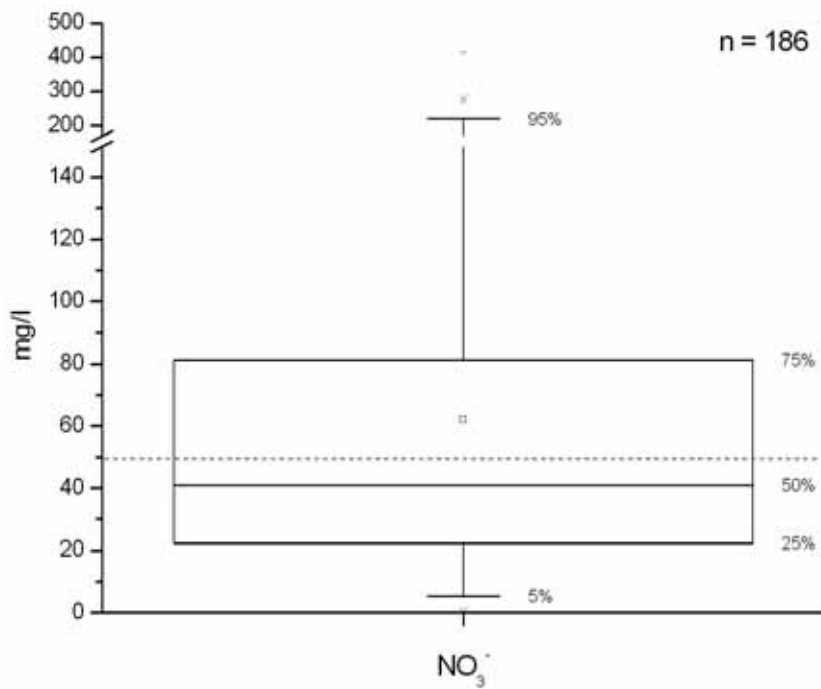
Fig. 3.19: Box-Whisker diagram of nitrate concentration in groundwater in the Kabul Basin 2004.
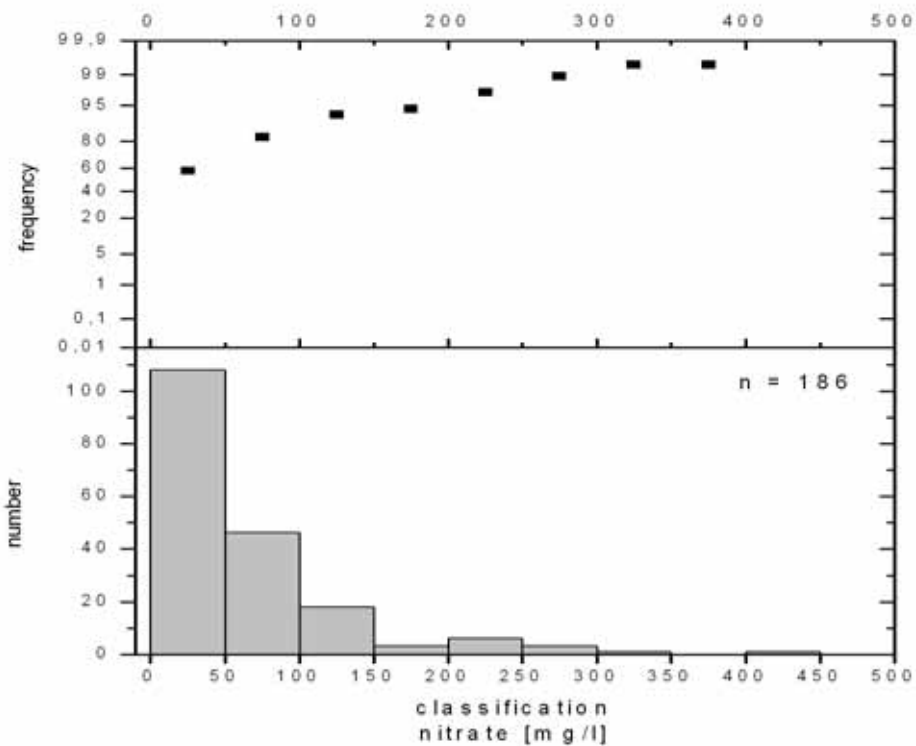
Fig. 3.20: Nitrate concentration histogram of groundwater in the Kabul Basin 2004.
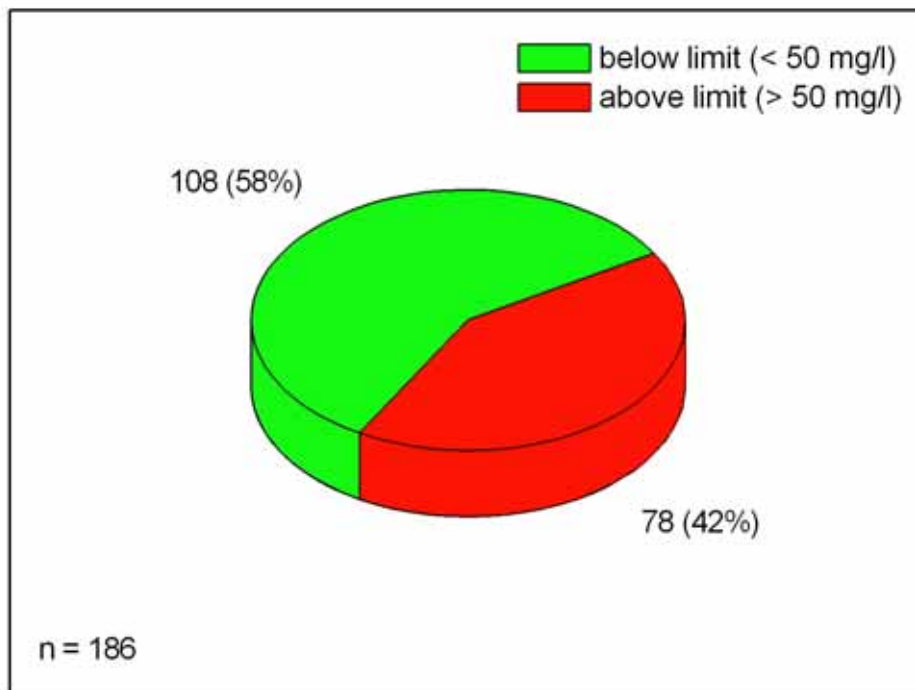
Fig. 3.21: Distribution of values exceeding the limits for nitrate in groundwater in the Kabul Basin 2004 in per cent.

There is no obvious trend in the spatial distribution of nitrate concentrations (Appendix 6). The southern sub-basin (Darulaman) generally has slightly lower values than the northern sub-basin, which may be attributable to the more scattered housing and the associated reduction in anthropogenic impact. In the inner city and the densely populated north-western district of Khair Khana in particular, there are local increases which may be attributable to sewage.

Because of its much higher toxicity, the drinking water limit for nitrite at 0.2 mg/l is much lower than the limit for nitrate. Because the groundwater in the Kabul Basin is oxidising almost throughout - albeit weakly oxidising – it is rare for nitrate to be reduced with the associated production of nitrite (Fig. 3.22). This is also indicated by the measured redox potentials (→ 3.4.1).

There is no correlation between raised nitrite levels and nitrate concentrations, i.e. the wells with high nitrate concentrations are not automatically also affected by raised nitrite concentrations (Fig. 3.23). There is also no clear correlation with redox potential. Wells with high nitrite concentration levels should also not be used to provide humans with drinking water.

The spatial distribution of nitrite concentrations does not reveal any clear picture (Appendix 7). There is a relative clustering of higher values in the inner city whilst the southern sub-basin (Darulaman) is slightly less contaminated.
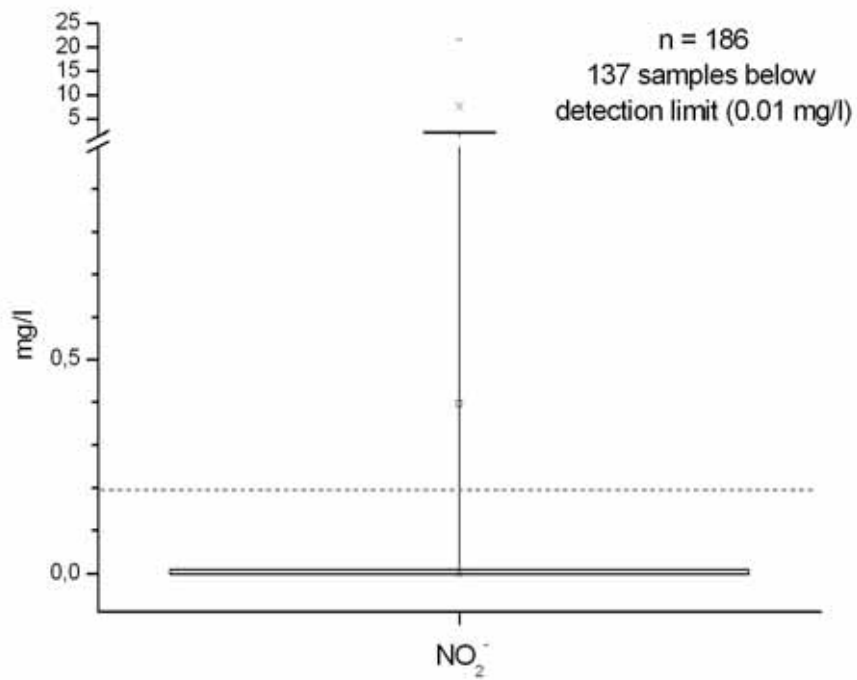
Fig. 3.22: Box-Whisker diagram of nitrite concentrations in the groundwater of the Kabul Basin 2004. Values below detection limit not shown.
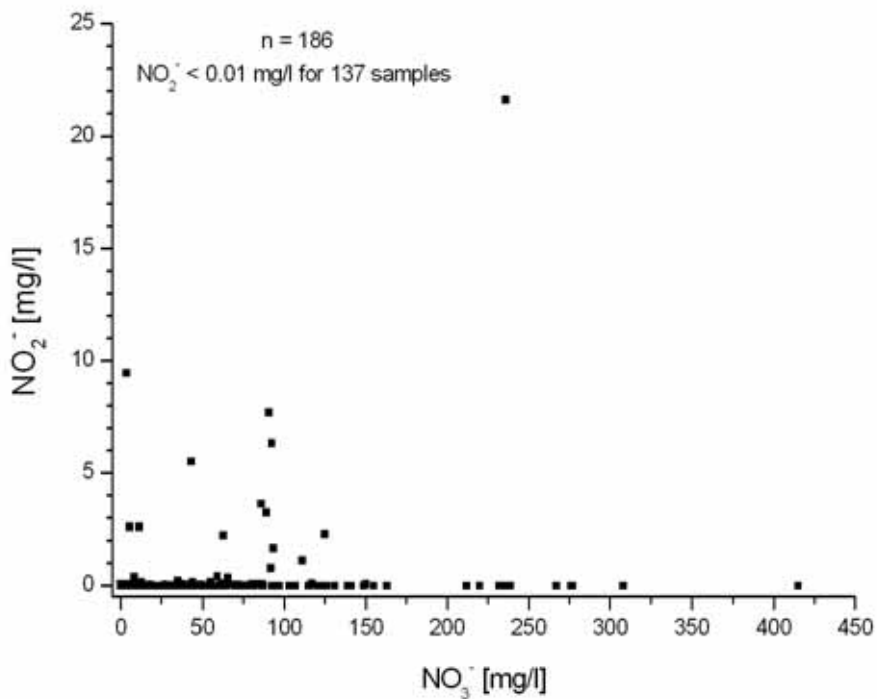
Fig. 3.22: Correlation between nitrite and nitrate concentrations in groundwater of the Kabul Basin 2004.

3.4.4 Iron and manganese

Iron and manganese have similar geochemical behaviour and can therefore be discussed jointly here. In their oxidised form (ferric iron, Fe(III), manganic manganese, Mn(III, IV)) they form solid oxides. These are dissolved under low redox potential conditions as reduced soluble species ferrous iron (Fe^{2+}) and manganous manganese (Mn^{2+}). Because of their tendency to oxidise and precipitate when they come into the contact with air – which can block wells and pipes ("incrustation") and discolour clothing – the levels for ferrous iron and manganese are restricted even though they are not actually harmful to humans.

The redox conditions of the groundwater in the Kabul Basin described in chapter 3.4.1 and 3.4.2 indicate that practically no iron can be mobilised from the aquifer at the measured redox potentials. The dissolved concentrations are therefore very low and very rarely exceed the limits, and then only slightly (Fig. 3.24).
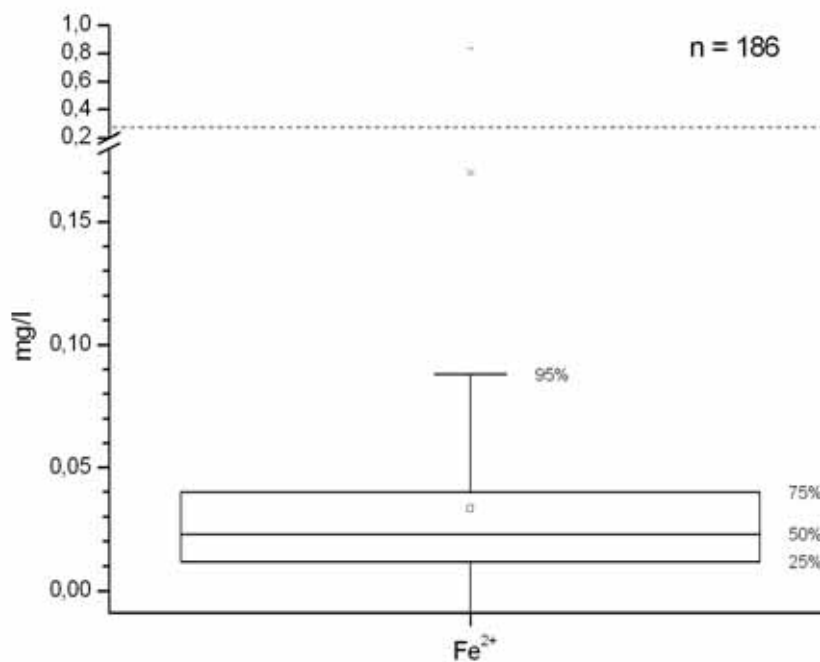
Fig. 3.24: Box-Whisker diagram of iron concentrations in the groundwater in the Kabul Basin 2004.

The measured redox potentials (→ 3.4.1) in the Kabul Basin cover the range indicating a reduction of manganese oxides and thus the mobilisation of manganese should be possible (Fig. 3.15). However, the measured concentrations are very low and only exceed the limits on rare occasions - as is also the case for iron - (Fig. 3.25). This anomaly is probably due to the lack of manganese oxides in the aquifer: manganese oxides are probably only present in small quantities, and only small quantities can be mobilised. Final clarification of this finding requires geochemical analysis of the solid aquifer materials.
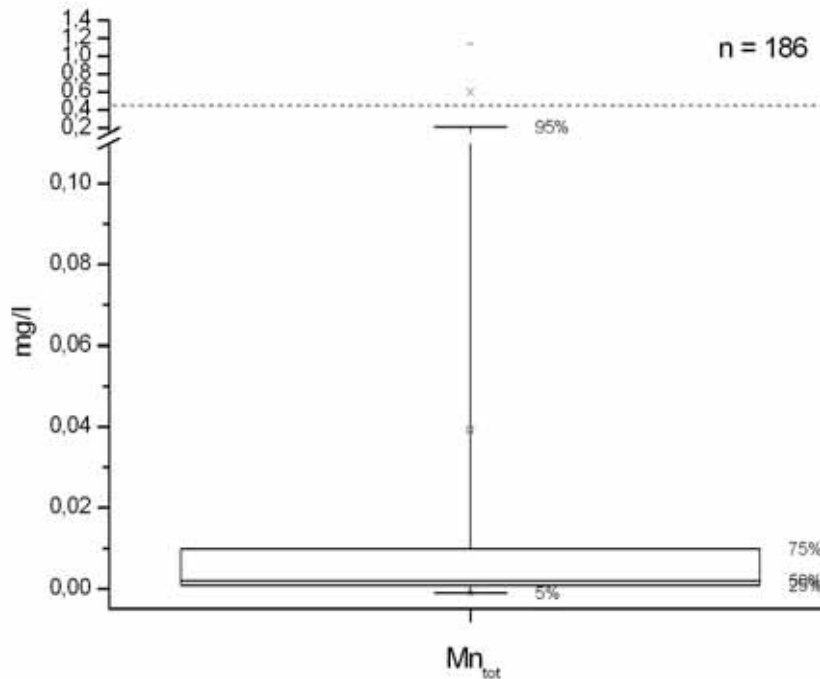
Fig. 3.25: Box-Whisker diagram of manganese concentrations in the groundwater in the Kabul Basin 2004.

3.4.5 Sulphate

The sulphate ion is a frequent constituent of groundwater. It can originate from various processes and sources:

- dissolution of gypsum ($CaSO_4 \cdot 2\ H_2O$) or anhydrite ($CaSO_4$) from the surrounding aquifer matrix
- oxidation of sulphides, e.g. pyrite (FeS_2), according to:
  $$2\ FeS_2 + 7\ O_2 + 2\ H_2O \Longleftrightarrow 2\ Fe^{2+} + 4\ SO_4^{2+} + 4\ H^+$$
- fertilisers
- immissions from the air, particularly as a result of "acid rain"
- sewage

Sulphate is relatively mobile in groundwater because it is hardly affected by sorption. The limiting phase can again be gypsum if the dissolution equilibrium is exceeded. Raised concentrations are undesirable for various reasons: gypsum can precipitate when sulphate-rich water is heated and therefore block water boilers for instance. High sulphate concentrations also have a laxative effect although the human body can develop a tolerance to concentrations up to approx. 500 mg/l.

The concentrations measured in the Kabul Basin are slightly raised throughout and around 17 % of the samples exceed the limits considerably in some cases (Fig. 3.26, 3.27). Because the loss of body fluid associated with the laxative effect can be dangerous for children in particular, the wells with strong sulphate contamination should no longer be used for human consumption. These wells are usually the same as the wells with elevated salinity anyway.
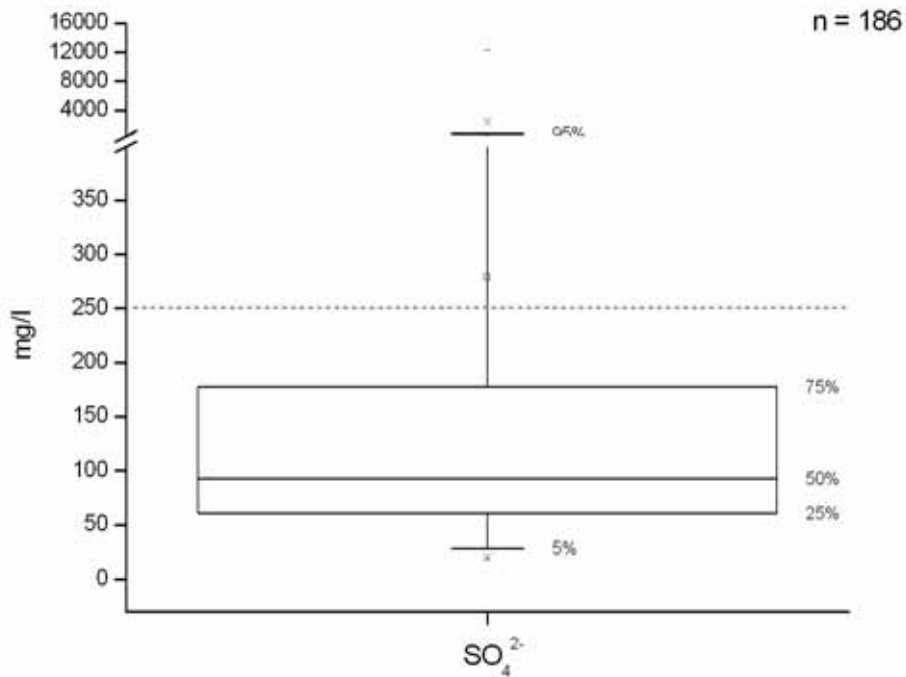
Fig. 3.26: Box-Whisker diagram of sulphate concentrations in groundwater in the Kabul Basin 2004.
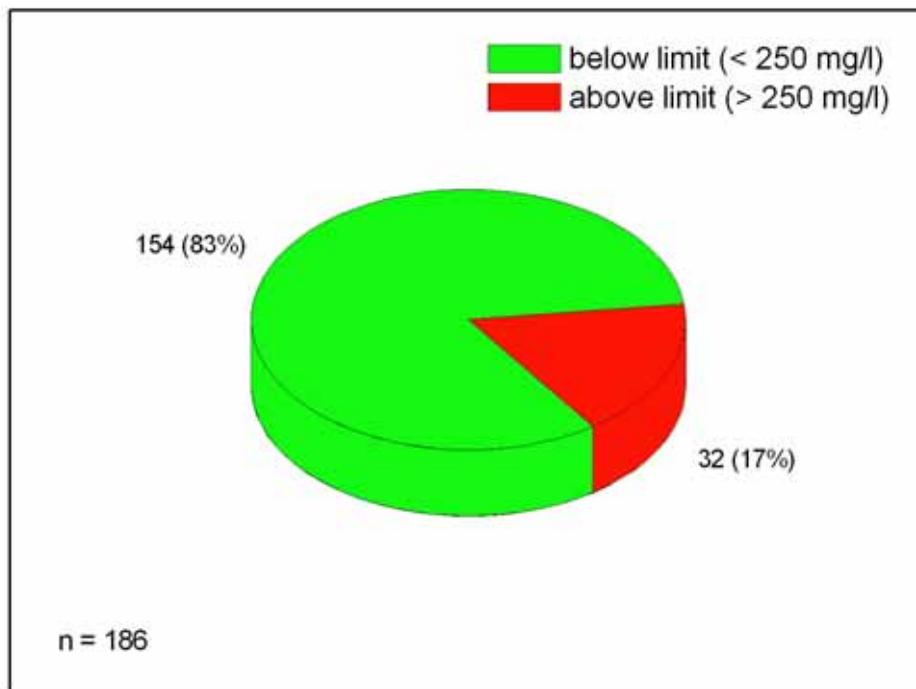
Fig. 3.27: Distribution of samples exceeding the limit for sulphate in the groundwater of the Kabul Basin 2004.

With regard to the spatial distribution of sulphate concentration, there is a higher level of contamination in the northern sub-basin than in the southern sub-basin

(Appendix 8). The inner city and the north-western district of Khair Khana in particular have slightly raised values. The highest values are associated with the dried-out swamps to the west of the airport ($\rightarrow$ 3.2) and are probably evaporitic.

A possible source or sink for sulphate could be gypsum ($CaSO_4 \cdot 2\,H_2O$) or anhydrite ($CaSO_4$) from the aquifer matrix. As shown in Fig. 3.28, concentrations of the bivalent main anions and cations can only be explained by a combination of carbonate and sulphate mineral equilibria. An equilibrium with carbonates alone is not sufficient to explain this effect ($\rightarrow$ 3.3.2, Fig. 3.11).
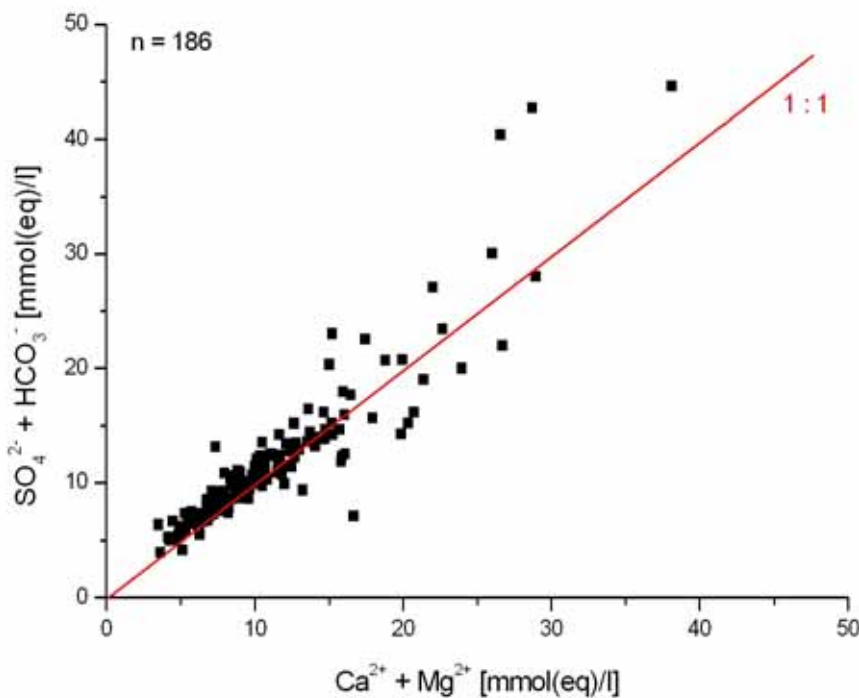
Fig. 3.28: Correlation between calcium and magnesium concentrations against concentration of hydrogen carbonate and sulphate in the groundwater in the Kabul Basin 2004.

However, the waters do not reach the saturation indices for gypsum anhydrite - with one exception - which means that these mineral phases cannot be precipitated out of the water (Fig. 3.29). Sulphate therefore originates in part from non-mineral sources, e.g. sewage.
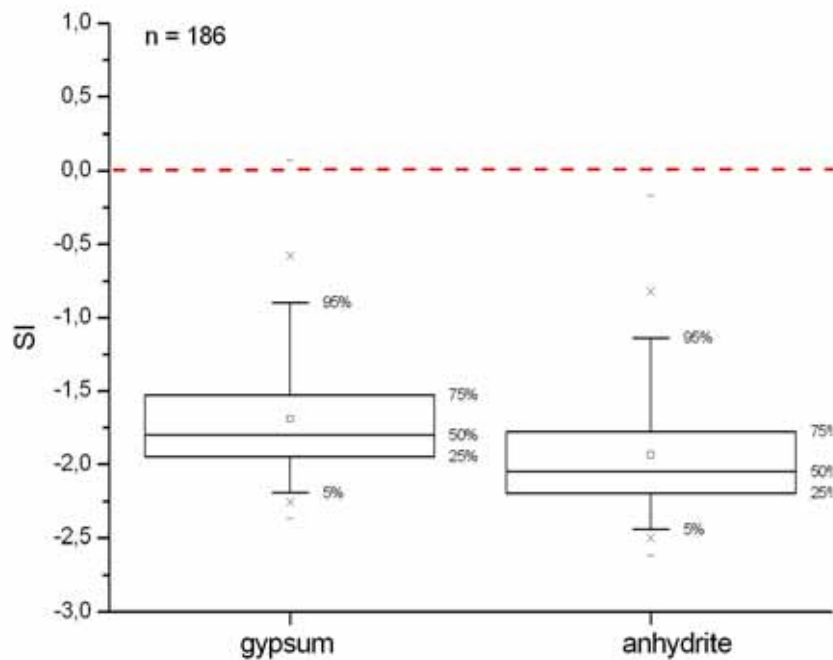
Fig. 3.29: Box-Whisker diagram of the saturation index (SI) of groundwater in the Kabul Basin 2004 for gypsum and anhydrite
SI > 0: water oversaturated, mineral phases can precipitate; SI < 0: water undersaturated, mineral phases can dissolve

Sulphate is converted by reduction to sulphide or hydrogen sulphide (H_2S) under very low redox potentials << 0 mV according to reaction (R 3.5). This is very easy to identify even at very low concentrations because of its characteristic "bad egg" smell.

$$2\ CH_2O + SO_4^{2-} \leftrightarrow H_2S + 2\ HCO_3^- \qquad\qquad (R\ 3.5)$$
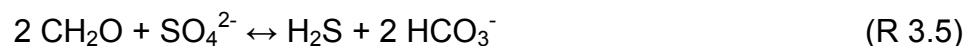
Such redox potentials were not recorded in our campaign ($\rightarrow$ 3.4.1). Although sulphide and hydrogen sulphide were not analysed as part of the sampling campaign discussed here, no samples contained no sulphate (Fig. 3.26), as would be the case with classic sulphate-reducing waters. In addition, no "bad egg" smells were noticed in the field. Given these findings, and the redox potential, it is clear that sulphate reduction does not play a role in the Kabul Basin - at least not with respect to shallow groundwaters.

3.5 Other dissolved salts
3.5.1 Sodium and chloride
Sodium and chloride ions are important constituents of most groundwaters. Because the limiting mineral sodium chloride (NaCl) is very soluble, both of the ions are very mobile. Both therefore become enriched in the residual solution during evaporation. Whilst the distribution of sodium is limited by ion exchange, chloride is a practically unreactive conservative tracer.

Sodium chloride is an essential nutrient for the human body. Adults have an average requirement of approximately 1.3 g/d. This is mainly covered by solid food. Drinking

water plays practically no role at all. Water with a chloride concentration above around 250 mg/l has a salty taste. Higher concentrations can cause considerable damage to the body's fluid balance. One of the negative effects of highly salty water is also the corrosion of metals.

The groundwater in the Kabul Basin has sodium and chloride concentrations whose median values are much higher than those of natural waters in humid regions (Fig. 3.30, 3.31). Because sea spray and de-icing salt can be ruled out here as sources, the salt concentrations measured here are probably the result of evaporation. Climatic data covering the Kabul Basin (see part I of this study) support this theory. However, some influence from sewage cannot be excluded.
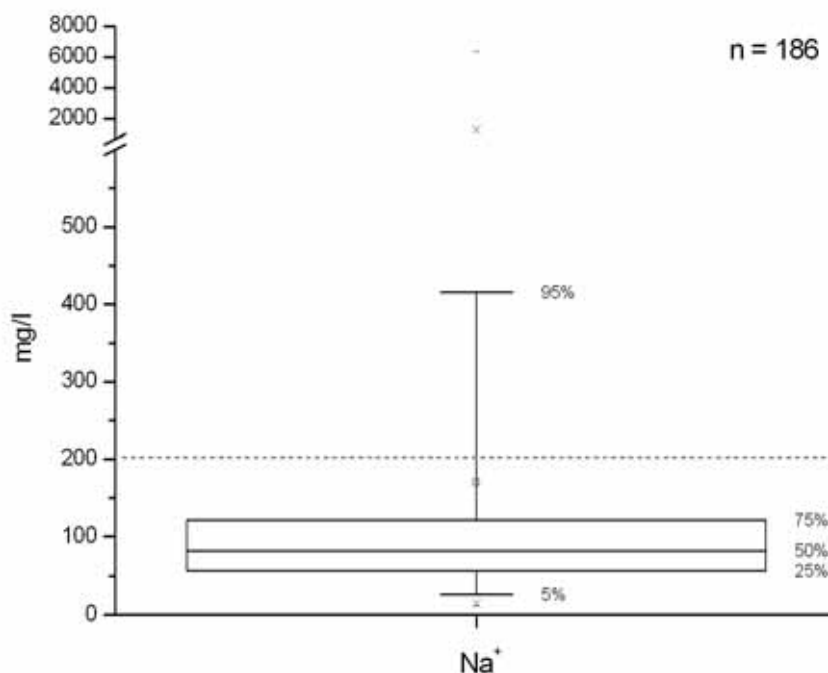
Fig. 3.30: Box-Whisker diagram of sodium concentrations in the groundwater of the Kabul Basin 2004.

26 of the investigated samples have excess levels of sodium, whilst 25 samples have excess amounts of chloride, i.e. approx. 14 % of all samples (Fig. 3.32). The two groups are congruent, i.e. when the limit for chloride is exceeded, it is also always exceeded for sodium - with one exception. Some of the concentrations of each of the ions exceeds 1000 mg/l. Water with these concentrations is unsuitable for human consumption, as well as being corrosive.
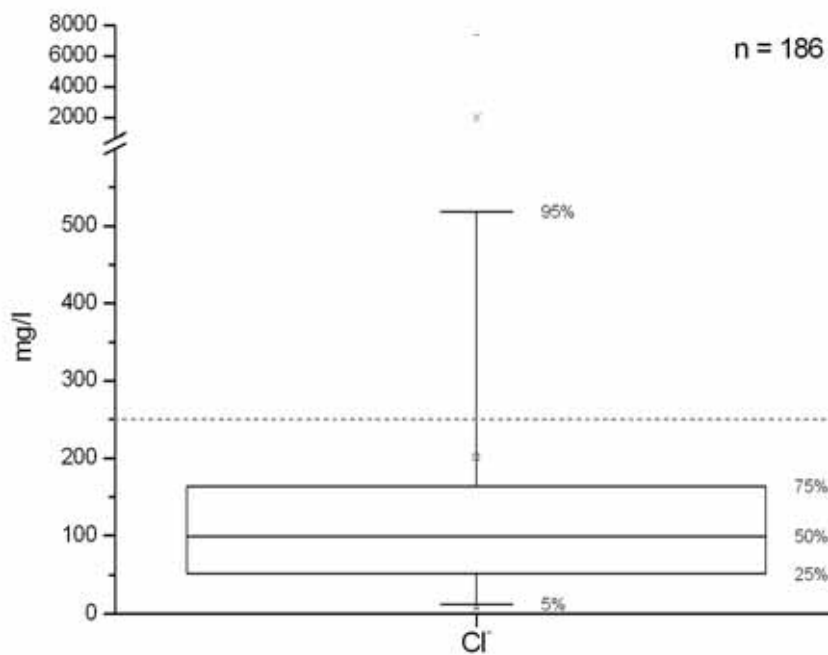
Fig. 3.31: Box-Whisker diagram of the chloride concentrations in groundwater of the Kabul Basin 2004.
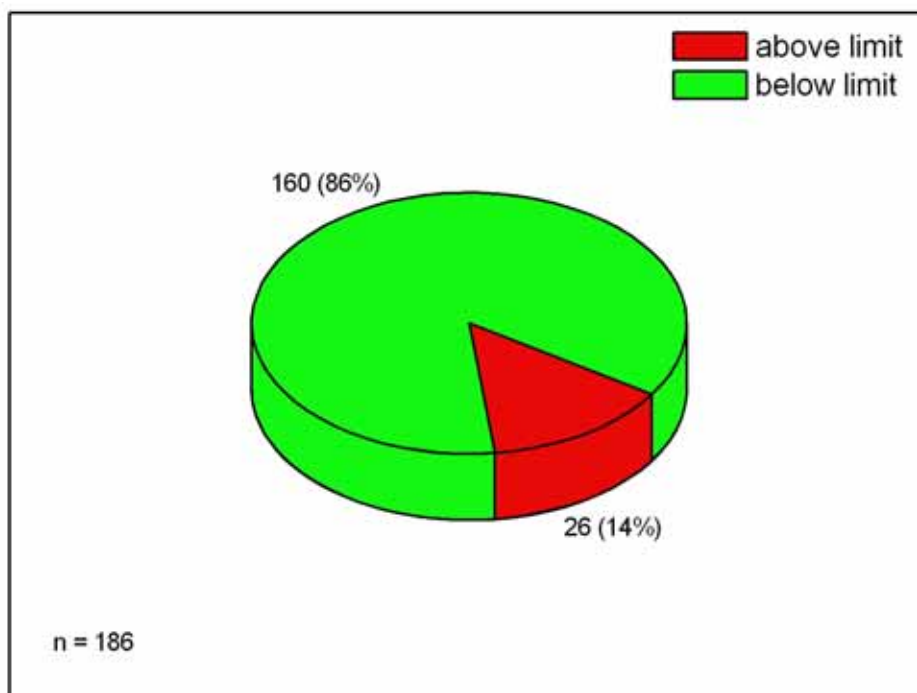
Fig. 3.32: Distribution of samples exceeding the limits for sodium and chloride in groundwater of the Kabul Basin 2004.

The correlation between sodium and chloride is very good which emphasises the importance of the sodium chloride constituent (Fig. 3.33). A slight excess amount of

Na can probably be attributed to other sodium sources such as sodium nitrate in sewage.
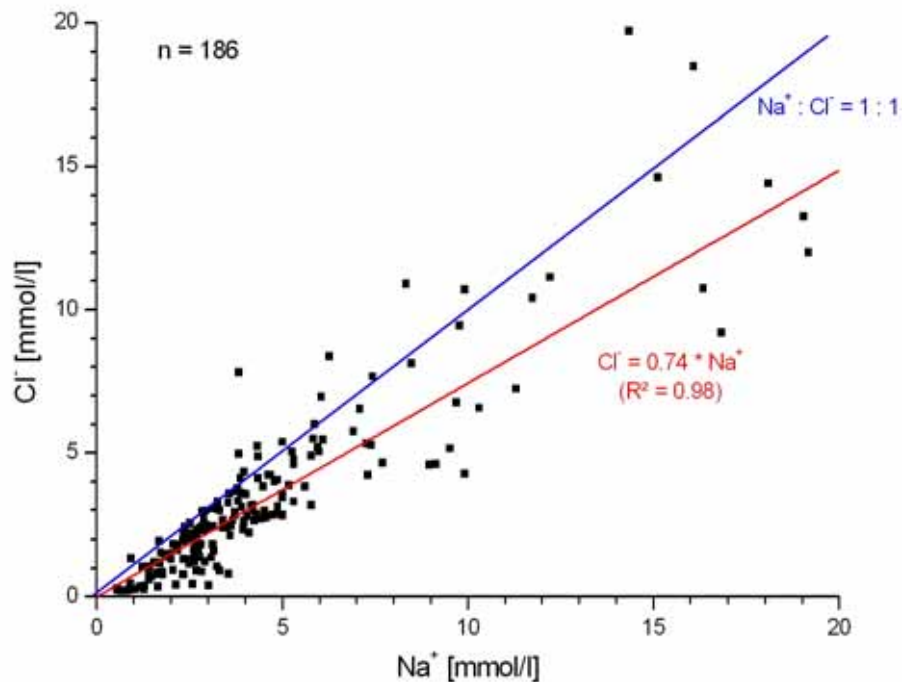
Fig. 3.33: Correlation of molar concentrations of sodium and chloride in groundwater of the Kabul Basin 2004.

With regard to spatial distribution, the cluster of raised Na^+ and /Cl- concentrations in the area to the west of the airport stands out from the rest ($\rightarrow$ 3.2). This area is the swampy zone with shallow groundwater which has dried out in recent years as a result of the drought. This has caused the dissolved salts to precipitate and become concentrated in the top soil. Soils can also become concentrated by the capillary rise of shallow groundwater to the surface.

3.5.2 Potassium

Potassium behaves in a similar geochemical way to sodium. It usually occurs in much lower concentrations in rocks and is more strongly retained (sorbed) by soil. Concentrations of potassium are therefore always lower than those of sodium. Values above an indicator level of 12 mg/l are a sign of salinised groundwater. Such concentrations do not represent a drinking water hygiene problem. There are hardly any raised potassium concentrations in the groundwater of the Kabul Basin. Higher values are only recorded in the more highly saline waters (Fig. 3.34).
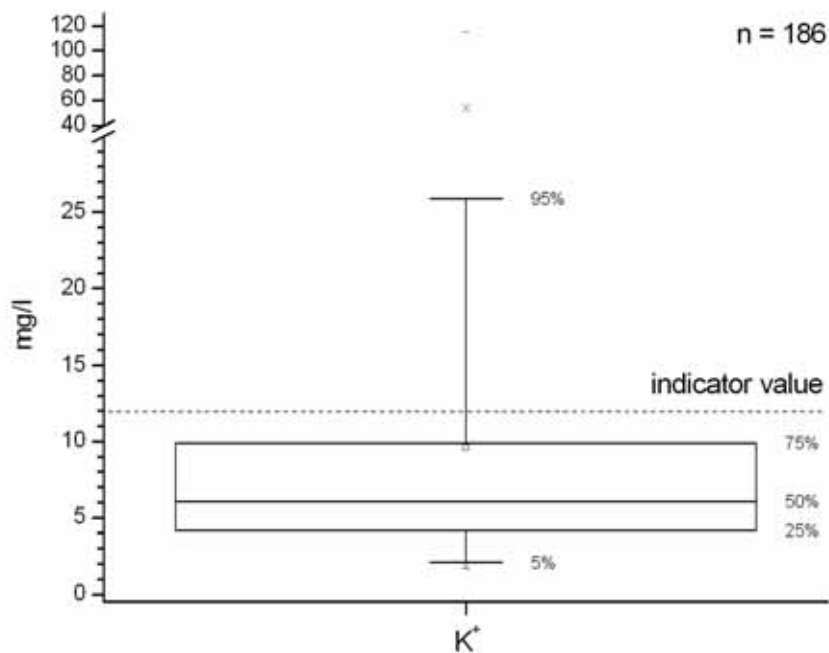
Fig. 3.34: Box-Whisker diagram of potassium concentration in the groundwater of the Kabul Basin 2004.

3.5.3 Borate

The element boron usually occurs in groundwater in the form of the anion borate. Because its toxicity to humans is fairly low, it has a relatively high EU limit of 1 mg/l (WHO 0.5 mg/l, B = approx. 2 mg/l BO_2). Boron is an essential trace element for fauna and flora. However, high concentrations in irrigation water can negatively affect the growth of plants ($\rightarrow$ 4.5). It can also become toxic for fish at higher concentrations in waters (10 - 300 mg/l).

Borate is a highly mobile ion. Due to the high solubility of boron minerals, borate can spread widely because it hardly ever precipitates. The spread is prevented to a minor degree by sorption, e.g. on iron oxide minerals.

Borate can be derived from various sources:

- many detergents contain sodium perborate ($NaBO_2(OH)_2$*3 H_2O) as the agent for oxidation. Because borate is formed by the release of hydrogen peroxide from the perborate, it is frequently used as an indicator for the immissions of domestic sewage. Concentrations of 0.1 mg/l boron (= 0.4 mg/l borate) are frequently found in sewage
- Borate becomes enriched in the residual solutions of evaporating water because boron minerals are highly water soluble and therefore only precipitate very late in the evaporation sequence,
- volcanic gases or volcanogenic thermal springs
- oilfield water
- weathering of the boron-bearing mineral tourmaline and to a lesser extent also biotite and amphibolite
- agricultural fertiliser (0.01 to 0.5 weight-% boron).

The first two processes mentioned above could take place in the Kabul Basin. Given the large population and the lack of any sewers or sewage treatment, it is probable that the boron represents contamination from domestic sewage. Because the use of modern detergents is much lower in Kabul than in the developed world because of the wide-spread poverty, the concentrations in the sewage in Kabul are probably quite small. However, the latest figures measured in the groundwater of the Kabul Basin are on average almost one order of magnitude above the figures for sewage in Germany (Fig. 3.35). They therefore almost reach the average figure for sea water of 4 to 5 ppm.

This means that there is either another natural source of boron or that the boron immissions have been concentrated by "recycling", i.e. being pumped up in hand-pumped wells and then percolating back down again with the sewage. The enrichment of borate here is probably due to evaporative processes. Evapo-transpiration in the Kabul Basin significantly exceeds precipitation in almost all the other months of the year (see Part I of this study).

A notable feature of the samples from the Kabul Basin is that only a few samples lie below the limit of 0.5 mg/l B or 2 mg/l BO_2 (Fig. 3.35, 3.36, 3.37). The USGS sampling campaign by Broshears et al. (2005) revealed a similar picture although the values were slightly lower (Fig. 3.37). The values in the urban areas are, however, higher than in the more rural surrounding area.

Because this is a widespread problem, it is not practical to instigate countermeasures such as abandoning wells (as required and possible in the case of nitrate/nitrate for instance). The only long-term solution here is the construction of a network of sewer pipes which helps to separate the wastewater from the groundwater. It is currently not possible to remove boron during drinking water treatment using conventional measures. Reverse osmosis would remove the boron but is much too expensive.
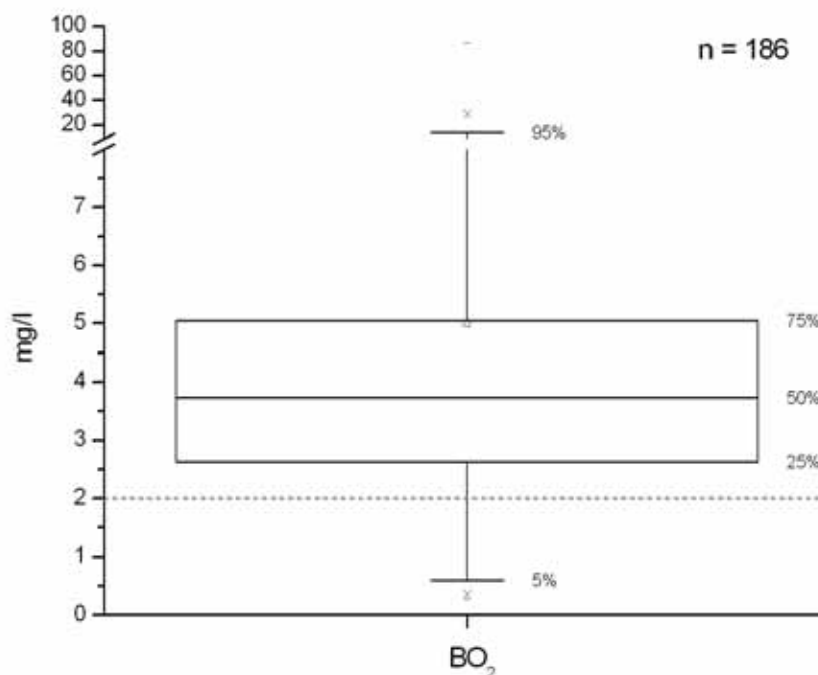
Fig. 3.35: Box-Whisker diagram of borate concentrations in the groundwater of the Kabul Basin 2004.
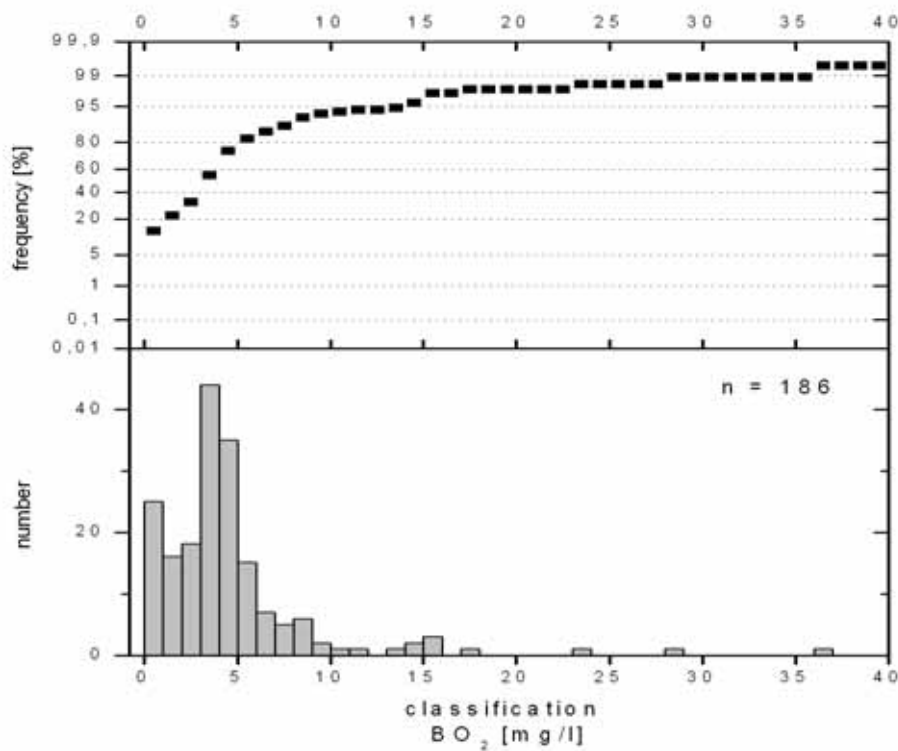
Fig. 3.36: Borate concentration histogram of groundwater in the Kabul Basin 2004.
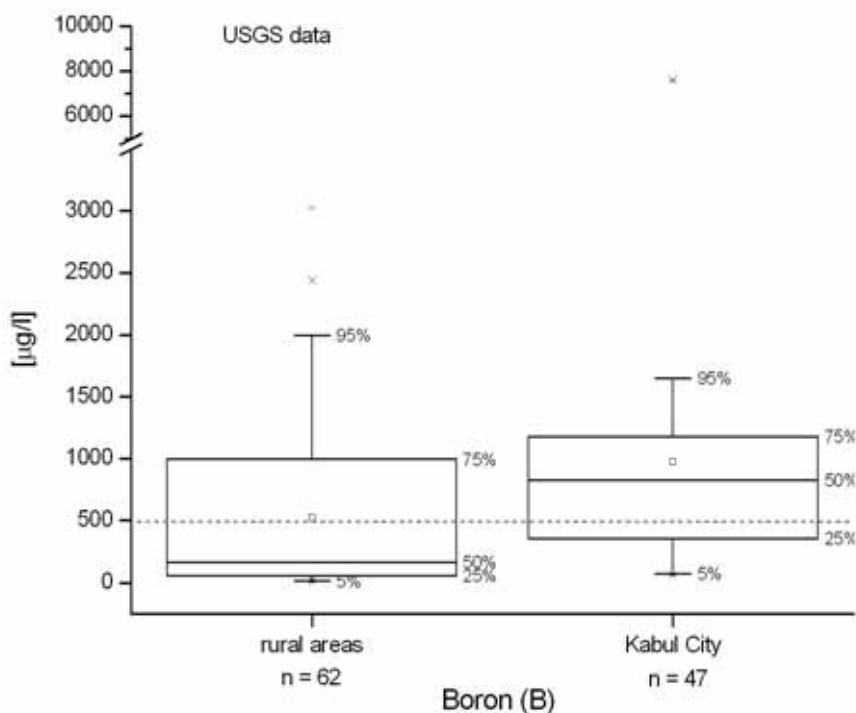
Fig. 3.37: Box-Whisker diagram of borate concentrations in groundwater in rural and urban parts of the Kabul basin 2004. After data from Broshears et al. (2005).

The spatial distribution of borate concentrations shows that the northern sub-basin is more strongly contaminated than the southern sub-basin (Appendix 9). The north-western basin margin of the northern sub-basin is also less contaminated than the

inner city areas. The highest figures are probably associated with evaporation in the swamp to the west of the airport.

The molar ratio of boron (borate) to chlorine (chloride) can be used as an indicator to determine the origin of the water. According to DAVIES & DE WIEST (1967) sea water and surface waters have a B/Cl ratio of 0.0002, whilst oilfield waters have a ratio of 0.02, and volcanogenic thermal waters a ratio of 0.1. The groundwater in the Kabul Basin has an average which lies between the two latter values (Fig. 3.38). The values therefore show an enrichment in boron compared to chloride as a result of the evaporative environment and recycling.
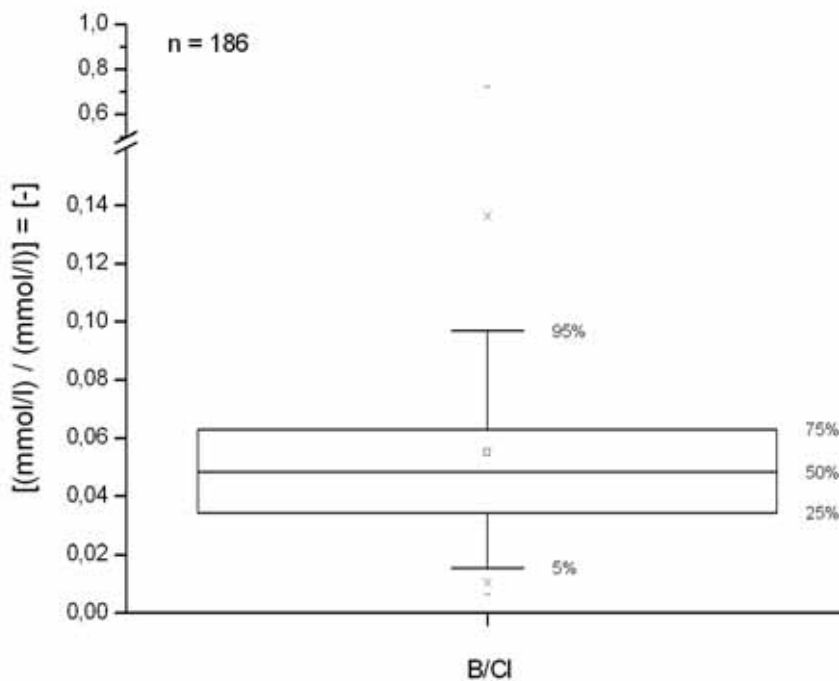
Fig. 3.38: Box-Whisker diagram of the molar boron/chloride ratio of groundwater in the Kabul Basin 2004.

3.5.4 Phosphate

Phosphate is an essential trace element for the growth of fauna and flora. The phosphate levels in sewage in Germany lie between 30 to 60 mg/l because of faecal immissions. Raised concentrations of phosphate in surface waters can give rise to algae blooms which indirectly causes strong oxygen depletion. Phosphate-rich water can also lead to the strong development of slime in pipes. However, it also protects metal components from corrosion ("phosphatising").

Because of its very high charge density, phosphate molecules are absorbed very strongly in soils so that groundwaters frequently only have low values. Iron oxides are particularly good sorbers. In groundwater, solubility is given an additional upward limit by the formation of the mineral calcium hydroxyl phosphate which restricts solubility to a maximum of approx. 5 mg/l.

Such limiting phenomena also appear to be present in the Kabul Basin because the phosphate concentrations in the groundwater are very low despite the obvious inflow

of domestic sewage and the associated phosphate contamination (Fig. 3.39). Phosphate is therefore not considered to be a risk to drinking water hygiene here. Because iron oxides are stable due to the measured redox potentials in the Kabul Basin groundwater (→ 3.4.1) it is expected that these play a major role in phosphate immobilisation.
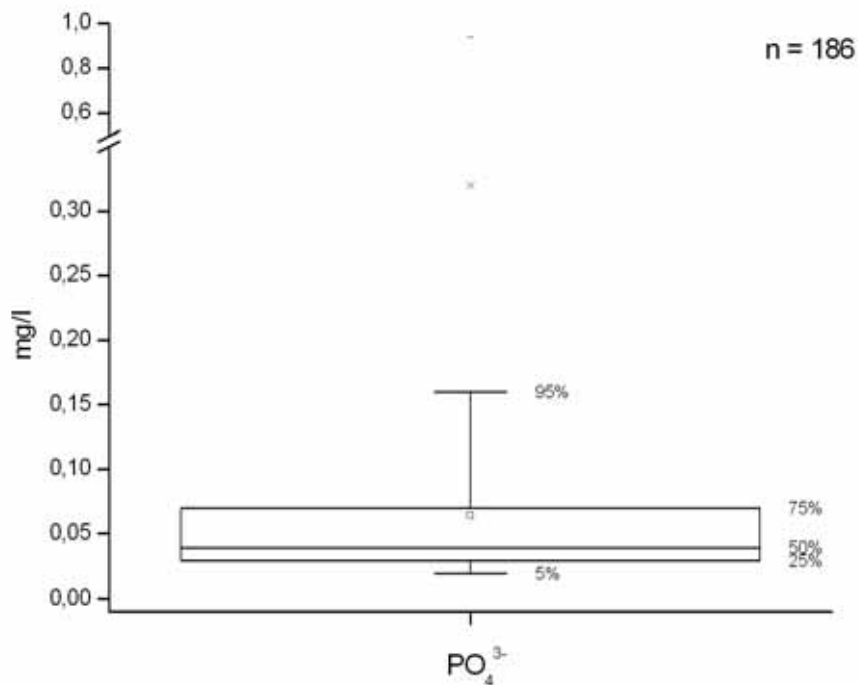
Fig. 3.39: Box-Whisker diagram of phosphate concentrations in the groundwater of the Kabul Basin 2004.

3.5.5 Silicon

Dissolved silicon is produced by the reaction of groundwater with the silicate constituents of the rocks forming the aquifer. Volcanic rocks, in particular those with large amounts of SiO_2 minerals of low crystallinity, are a major source of silicon. Solubility is strongly pH-dependent and reaches its maximum in particularly acid or especially basic waters.

Although the silicon concentrations in the Kabul Basin are higher than in most Central European groundwaters, this does not have a negative effect on the hygiene of the drinking water (Fig. 3.40). A neutral groundwater pH limits its mobilisation. However, the use of such water in boilers etc. can give rise to the formation of silicate precipitates which are very difficult to remove and could therefore block the appliances (→ 4.4).
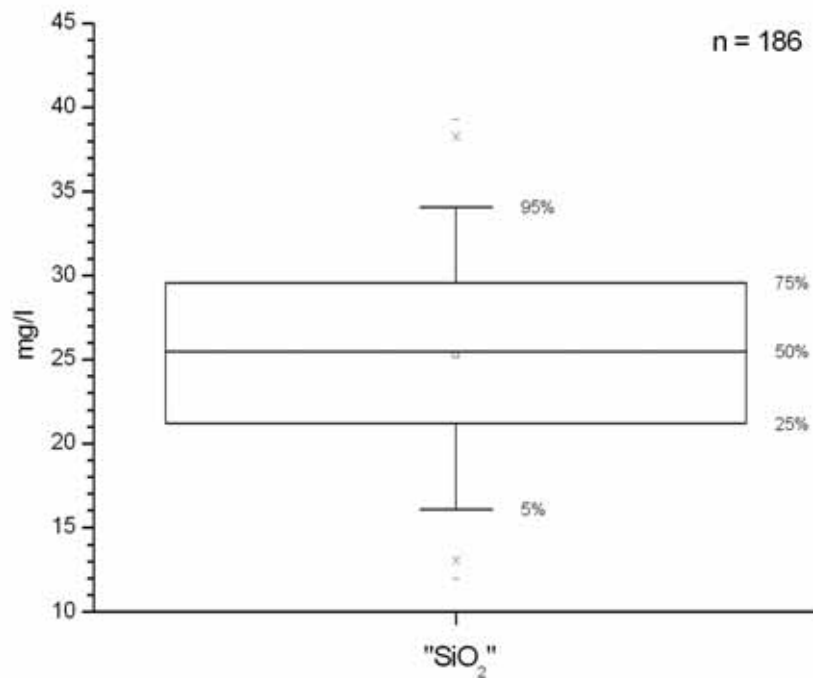
Fig. 3.40: Box-Whisker diagram of silicon concentration (as SiO_2) in the groundwater of the Kabul Basin 2004.

3.5.6 Fluoride

Whilst low concentrations of fluoride in drinking water are hygienically desirable, e.g. to strengthen teeth, the long-term drinking of water with raised fluoride concentrations can give rise to fluorosis, a disease which initially damages the teeth and in serious cases can have a negative effect on bones and joints as a result of stiffening. Such high concentrations are often found in areas with granitic rocks.

Despite the presence of crystalline rocks in the surrounding area (see part I of this study), the aquifers of the Kabul Basin hardly contain any fluoride or release any fluoride because the concentration in the groundwater exceeds the limit of 1.5 mg/l slightly in only one case (Fig. 3.41). Fluoride is therefore of no relevance here for drinking water hygiene.
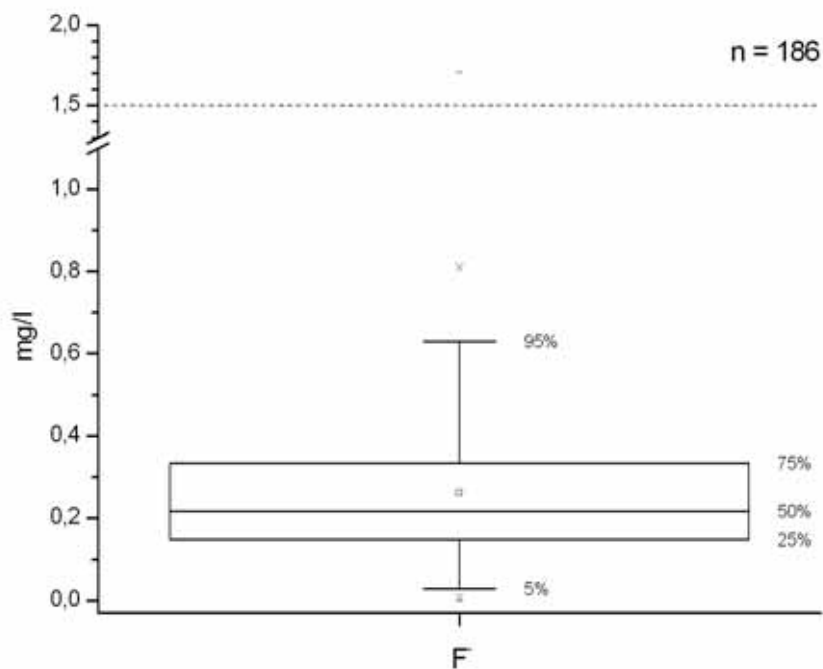
Fig. 3.41: Box-Whisker diagram of fluoride concentration in the groundwater of the Kabul Basin 2004.

3.5.7 Barium

Barium usually only occurs in groundwater in very low concentrations because its mobility is strongly limited by the presence of sulphate resulting in the formation of the poorly soluble mineral phase baryte ($BaSO_4$). This means that hygienically-relevant concentrations are virtually never found.

Because the water in the Kabul Basin has fairly high sulphate concentrations throughout, the low barium concentrations are of no surprise (Fig. 3.42, 3.43). The EU limit of 1.0 mg/l is never reached. Barium is therefore of no drinking water hygiene significance here.

Figure 3.43 shows that the barium concentration is limited by the sulphate. Waters are therefore largely oversaturated with respect to baryte (Fig. 3.44). The possible precipitation of baryte in pipes etc. is negligible because of the low concentrations.
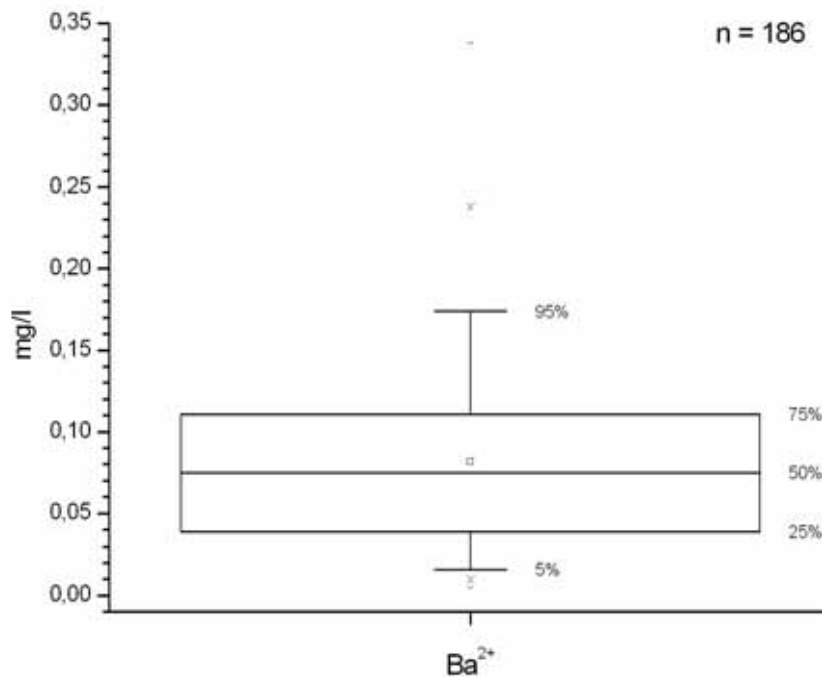
Fig. 3.42: Box-Whisker diagram of barium concentrations in the groundwater of the Kabul Basin 2004.
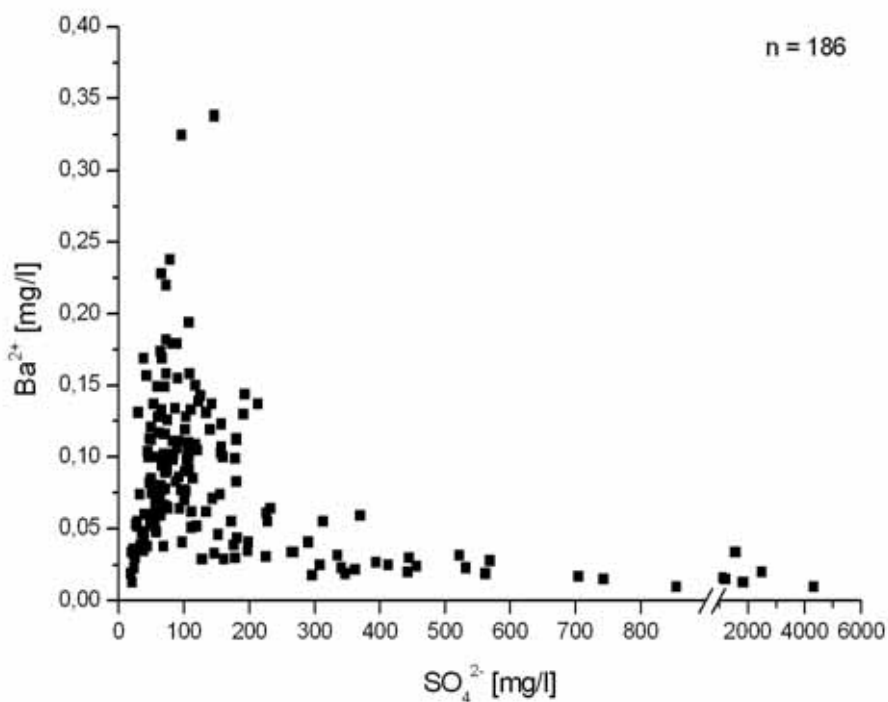
Fig. 3.43: Correlation between sulphate and barium concentrations in the groundwater of the Kabul Basin 2004.
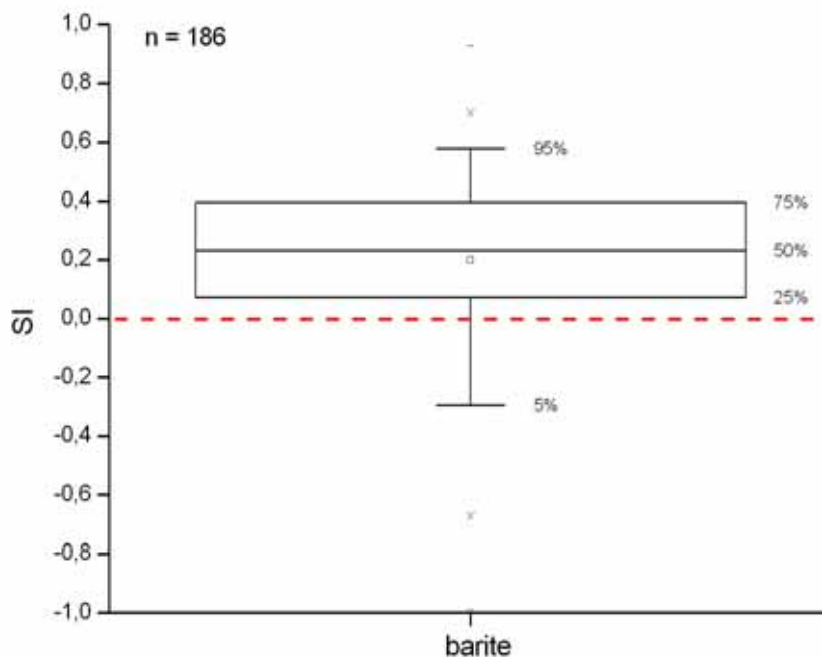
Fig. 3.44: Box-Whisker diagram of the saturation index (SI) of groundwater of the Kabul Basin 2004 with respect to baryte.
SI > 0: water oversaturated, mineral phase can precipitate; SI < 0: water undersaturated, mineral phase can dissolve.

3.5.8 Bromide

Bromide and chloride are halogenides and have similar geochemical behaviour. They occur together in saline waters. Because bromide is much less common in the earth's crust than chloride, it usually only occurs in very low concentrations in groundwater.

The average concentrations are also fairly low in the Kabul Basin (Fig. 3.45). The dominant species bromide (Br-) therefore has practically no significance in groundwater with respect to drinking water hygiene. However, high bromide concentrations in water are undesirable because the chlorination during water treatment of such water causes bromide to oxidise to bromine, which in the presence of dissolved organic carbon (DOC) reacts further to produce bromine hydrocarbons (e.g. tribromomethane = bromoform) which is a problem for drinking water hygiene. Because of their toxicity, the limits for these compounds are very low at 100 µg/l.

Because bromine (bromide) is a companion element of chloride - with similar chemical properties - their concentrations are normally associated with salt-rich waters. In seawater and most groundwaters, the molar chloride/bromide ratio is around 300:1. As expected, the Kabul Basin waters have a good correlation between bromide and chloride (Fig. 3.46). Problematic bromide concentrations are therefore present in waters which are already unsuitable for human consumption because of their salt content.
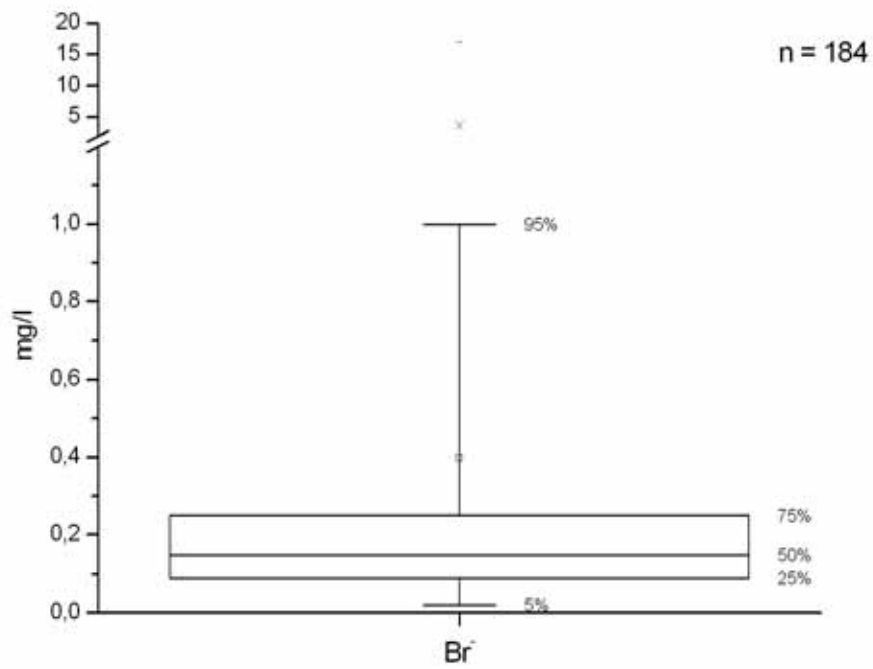
Fig. 3.45: Box-Whisker diagram of bromine concentrations in the groundwater of the Kabul Basin 2004.
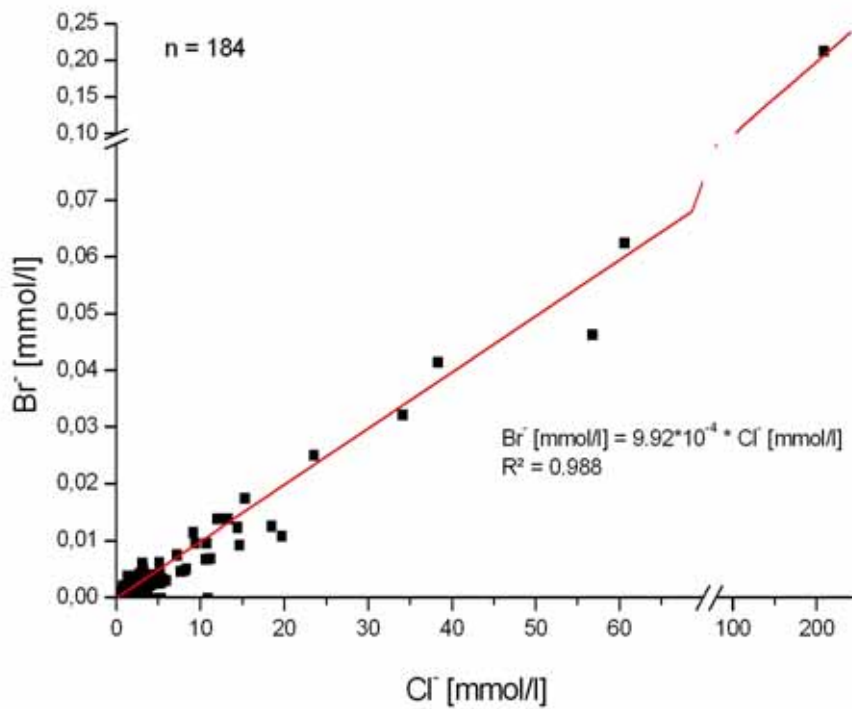
Fig. 3.46: Correlation between molar bromide and chloride concentrations in the groundwater of the Kabul Basin 2004.

The anions bromide and chloride may have similar chemical behaviour, but they do behave differently under very strong evaporation conditions. Because the bromide salts are even more soluble than those of chloride, chloride precipitates out first, usually in the form of sodium chloride (NaCl). This enriches the residual solution with bromide - in a similar way to borate ($\rightarrow$ 3.5.3). The molar Cl/Br ratio in figure 3.46 is around 1000:1 and therefore much higher than for seawater and normal groundwaters. This is another clear sign of the influence of evaporation on the groundwater.

The correlation between borate and bromide, or the trend at least, indicates that both have become relatively enriched as a result of evaporation (Fig. 3.47). It is therefore unlikely that borate only comes from detergents ($\rightarrow$ 3.5.3).
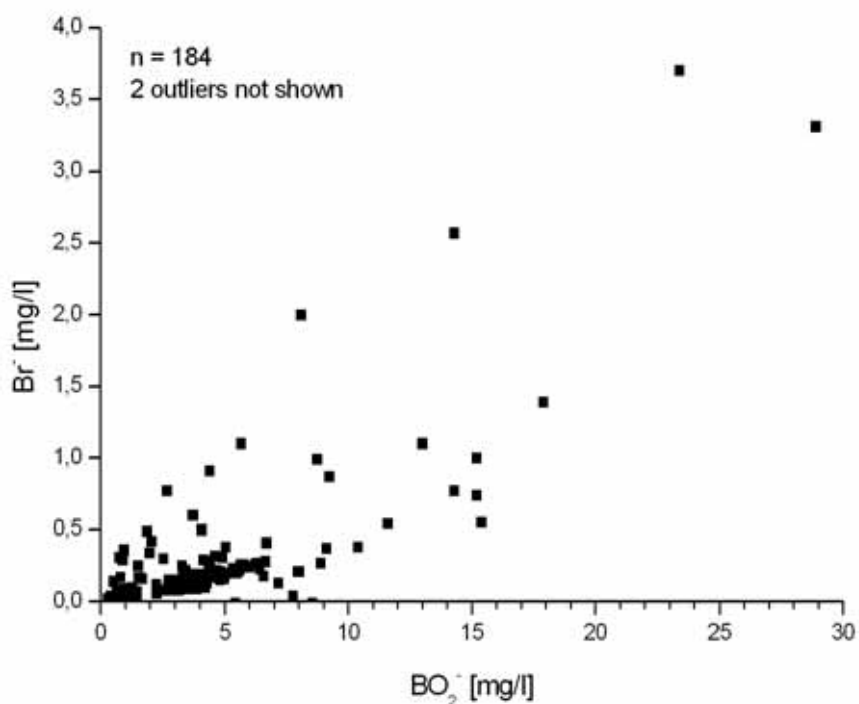
Fig. 3.47: Correlation between the bromide and borate concentrations of the groundwater of the Kabul Basin 2004.

3.5.9 Strontium

Strontium is a frequent secondary component of carbonate minerals because of its similarity in geochemical behaviour to calcium and can therefore be incorporated into the lattice of carbonate minerals. It can also form its own minerals such as strontianite ($SrCO_3$) and celestite ($SrSO_4$).

Strontium in the Kabul Basin occurs in concentrations of a few milligrams per litre (Fig. 3.48). These figures are therefore of no significance for drinking water hygiene here because strontium is neither toxic nor essential. There are therefore no regulations or limits. The dependence of strontium on calcium concentrations is also clearly visible (Fig. 3.49).
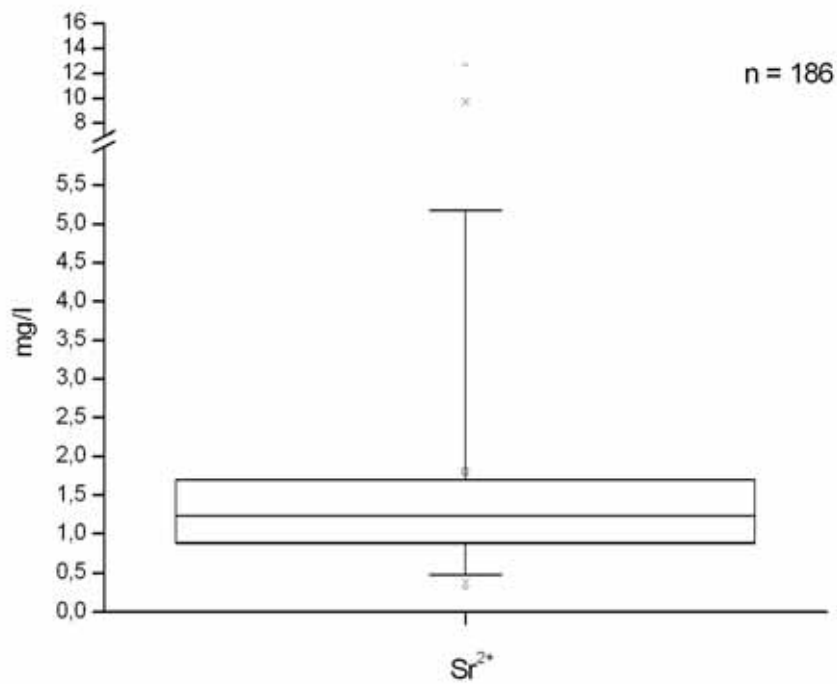
Fig. 3.48: Box-Whisker diagram of strontium concentrations in the groundwater of the Kabul Basin 2004.
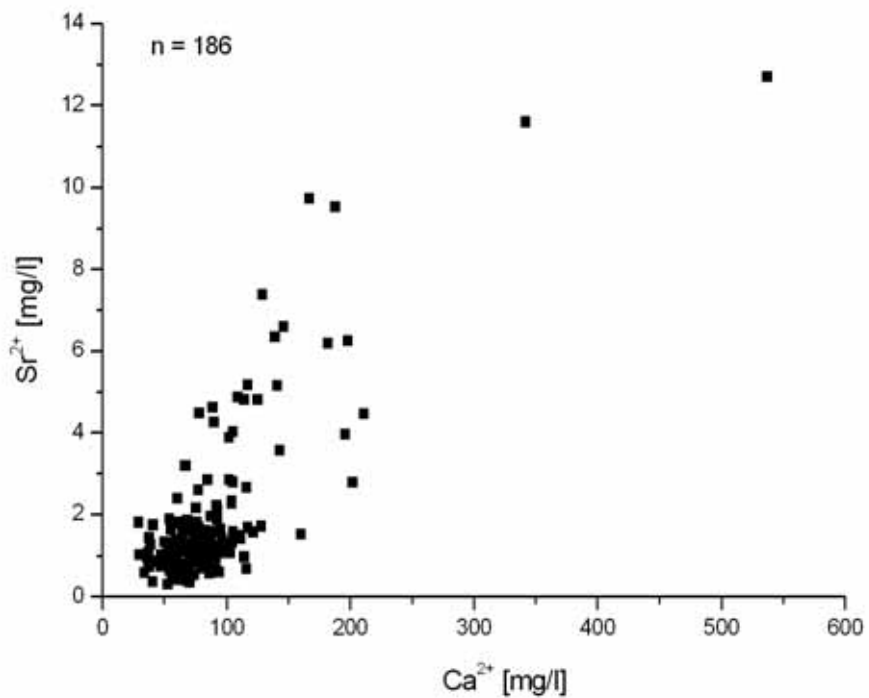
Fig. 3.49: Correlation between calcium and strontium concentrations in the groundwater of the Kabul Basin 2004.

Because the concentration of strontium is less than 14 mg/l throughout, the solubility product for celestite is not reached, despite the high sulphate concentrations. The same applies even more to strontianite (Fig. 3.50).
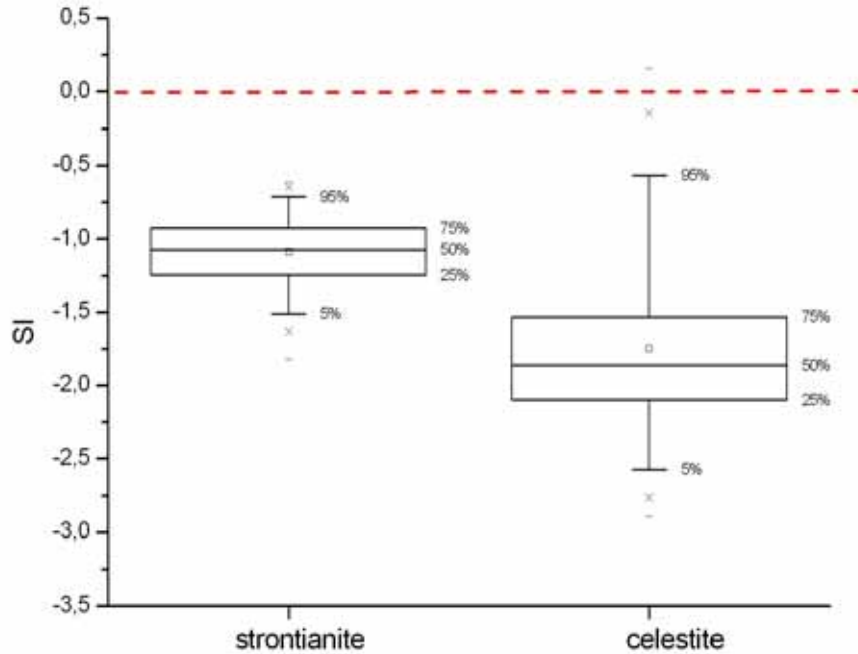
Fig. 3.50: Box-Whisker diagram of the saturation index (SI) of groundwater of the Kabul Basin 2004 with respect to strontianite and celestite.
SI > 0: water oversaturated, mineral phase can precipitate; SI < 0: water undersaturated, mineral phase can dissolve.

3.5.10 Lithium

Lithium is geochemically closely related to sodium and potassium and its presence is therefore linked to these elements. However, it occurs naturally in much lower concentrations. It has no significance for drinking water hygiene and there are therefore no limits. The values in the Kabul Basin are low and more or less linked to the sodium concentrations (Fig. 3.51).
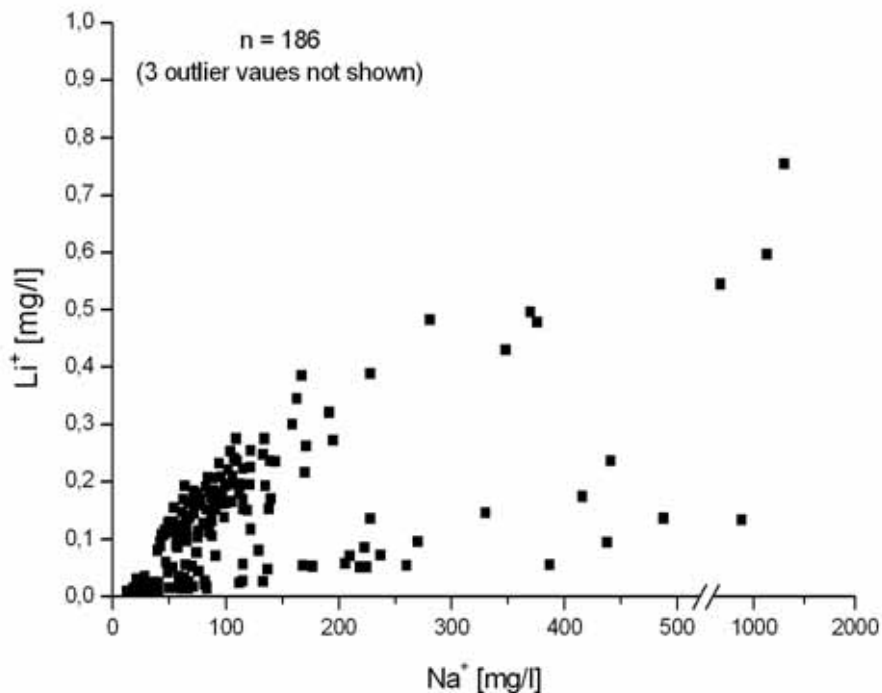
Fig. 3.51: Correlation between sodium and lithium concentrations in the groundwater of the Kabul Basin 2004.

3.6 (Heavy) metals and metalloids

3.6.1 Aluminium
Water with a low pH can dissolve the solid constituents of soil and/or desorb metal ion sorbed on the soil matrix. At a pH below 3.5, aluminium can become mobilised in accordance with reaction equation (R 3.6). This is undesirable because of its toxicity to plants and the possible development of incrustations.

$$Al(OH)_3 + 3\ H^+ \leftrightarrow Al^{3+}_{(aq)} + 3\ H_2O \hspace{2cm} (R\ 3.6)$$
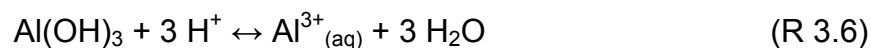
Mobilisation of this kind can be excluded given the measured pHs ($\rightarrow$ 3.3.1). The measured concentrations of dissolved aluminium are thus very low and lie below the limit in almost every case (Fig. 3.52). The exceptions are probably due to suspended material or colloids not filtered out of the water samples. Because these frequently consist of aluminium-bearing clay minerals, they can give rise to aluminium concentrations of this kind during analysis.
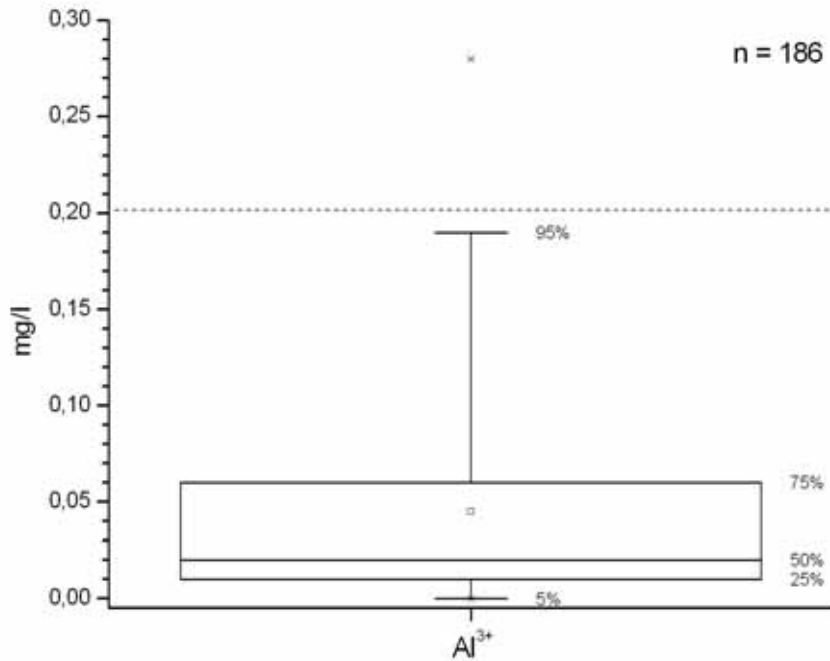
Fig. 3.52: Box-Whisker diagram of aluminium concentrations in the groundwater of the Kabul Basin 2004.

3.6.2 Zinc

Zinc is a well-known example of a metal ion that can be desorbed from the soil matrix in low pH water or mobilised in a reducing redox environment. Because it is an essential trace element for human health and has relatively low toxicity for a heavy metal, the WHO limit is relatively high at 4 mg/l.
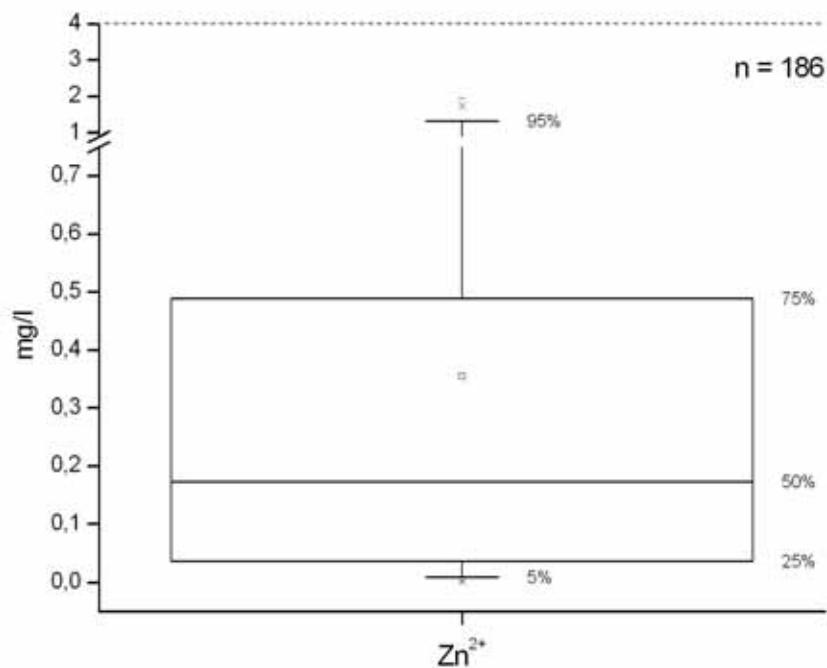
Fig. 3.53: Box-Whisker diagram of zinc concentrations within the groundwater of the Kabul Basin 2004.

Because the pH and redox conditions in the Kabul Basin lie in the neutral to weakly oxidising range, the zinc concentrations are always below this limit (Fig. 3.53).

3.6.3 Nickel

Iron oxide and manganese oxide can absorb large amounts of heavy metals and metalloids. Well-known examples are nickel and arsenic. These trace elements can be mobilised in groundwater by dissolution under acid conditions. Although nickel can also be mobilised under low pH conditions, this is not associated with any risk ($\rightarrow$ 3.3.1).

Because of the redox-related stability of the iron oxides and manganese oxides in the Kabul Basin, the nickel concentrations are very low. Only one sample exceeded the limit of 0.05 mg/l (Fig. 3.54). Most of the samples are well below the limit and some even below the detection limit.
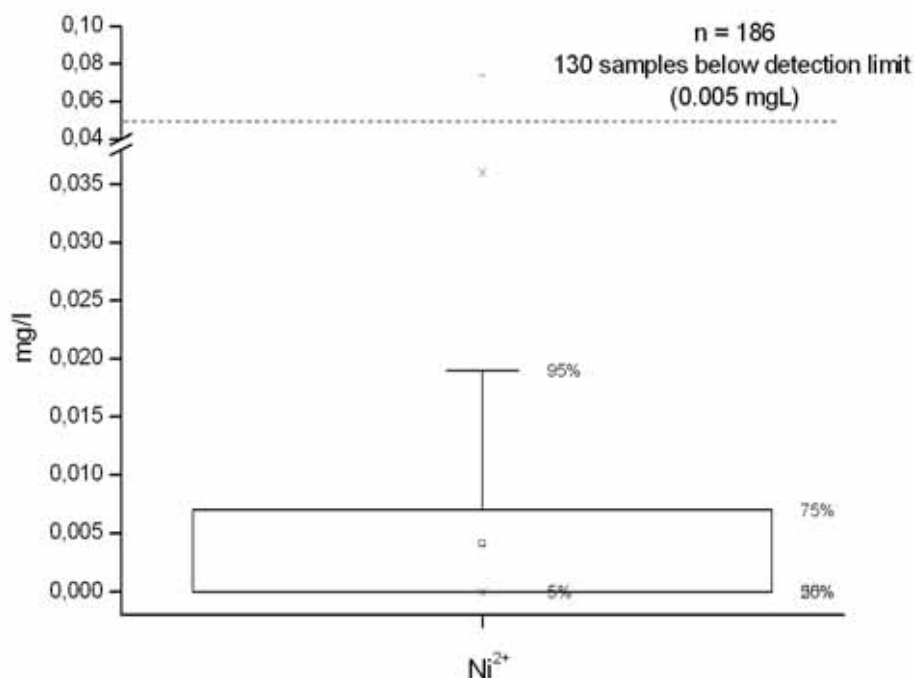
Fig. 3.54: Box-Whisker diagram of nickel concentrations in the groundwater of the Kabul Basin 2004. Values below detection limit not shown.

3.6.4 Copper

Copper is an essential trace element and of major importance for human, animal and plant nutrition. Humans can tolerate up to 0.05 to 0.5 mg copper per kg body weight. The WHO limit for drinking water is thus set at a high level of 5 mg/l.

The samples from the Kabul Basin all have very low values (Fig. 3.55). Copper therefore has no relevance to the hygiene of drinking water in the Kabul Basin. Mobilisation by the reduction of iron oxides and the effect of acids is also unlikely here because of the redox and pH conditions described earlier ($\rightarrow$ 3.3; 3.4).
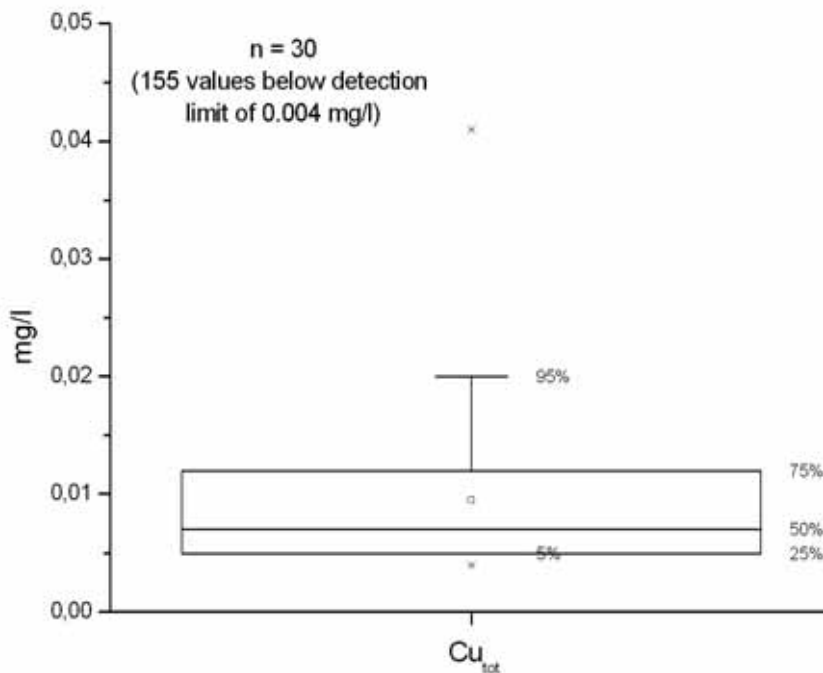
Fig. 3.55: Box-Whisker diagram of copper concentrations in the groundwater of the Kabul Basin 2004. Values below detection limit not shown.

3.6.5 Arsenic

Because of its strong toxicity, arsenic has very low limits of 0.01 mg/l. Lethal doses range from 5 to 50 mg As. The long-term consumption of arsenic-bearing water can cause necrosis ("blackfoot disease") and cancer. Arsenic was often used in the past as the active substance in pesticides. It is also possible for natural occurrences to be present in groundwater. They are bound to sulphides or iron oxides and manganese oxides which can accommodate significant quantities of arsenic. This arsenic can be mobilised in the groundwater by the dissolution of the oxides under strongly reducing redox conditions.

The mobilisation of arsenic in the Kabul Basin is considered unlikely because of the redox and pH conditions described earlier ($\rightarrow$ 3.3; 3.4). This proved to be the case because only 3 of the 167 investigated samples exceeded the limit (Fig. 3.56). However, even the concentrations in the samples exceeding the limit are not high enough to represent an immediate risk.
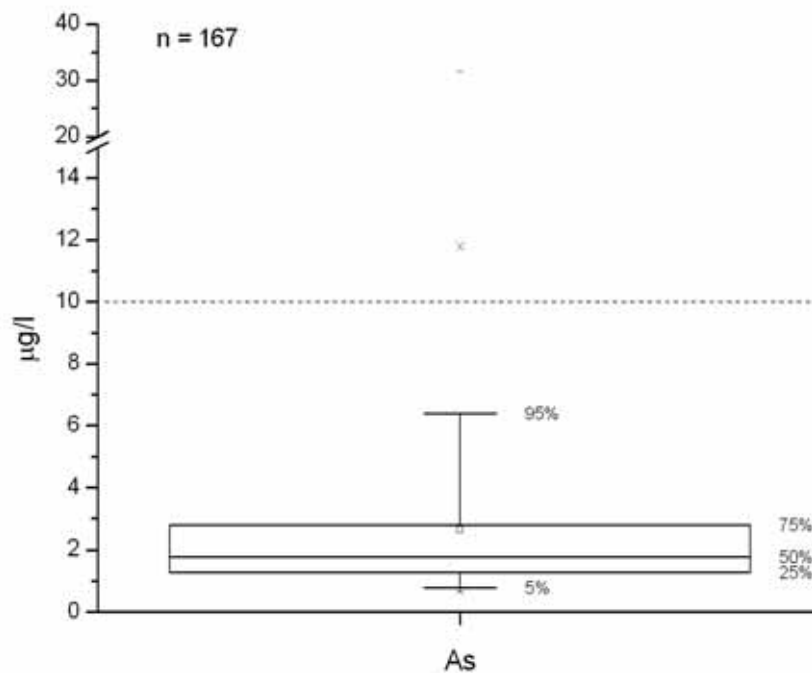
Fig. 3.56: Box-Whisker diagram of arsenic concentrations in the groundwater of the Kabul Basin 2004.

3.6.6 Mercury

Mercury is used in dental fillings, metal vapour lamps and thermometers. It was also frequently used in the past as an active substance in pesticides. Natural occurrences are particularly associated with sulphides. Because of its high toxicity, mercury is assigned a very low limit of 0.001 mg/l. Mercury could not be determined in this study because of the sampling methods used.

3.6.7 Chromium

Chromium is an essential trace element. Only the hexavalent species is of any toxicological significance because of its strong oxidising properties, e.g. used for leather tanning.

Most of the samples from the Kabul Basin had very low to undetectable concentrations of chromium (Fig. 3.57). The limit was only barely exceeded in three cases. It is therefore generally not thought to have any significance for drinking water hygiene in the area.
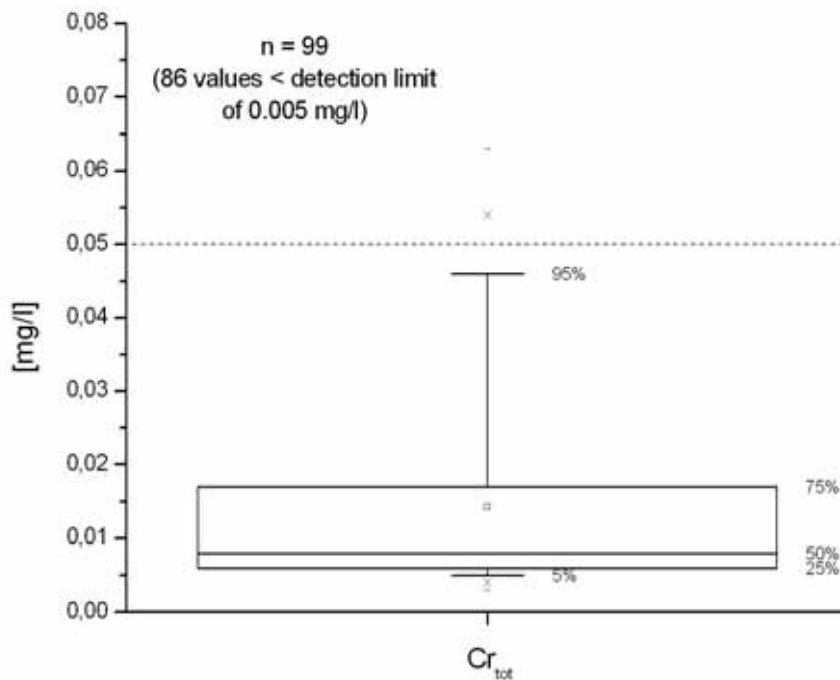
Fig. 3.57: Box-Whisker diagram of chromium concentrations in the groundwater of the Kabul Basin 2004. Values below detection limit not shown.

3.6.8 Vanadium

Analysis for vanadium is only carried out rarely in groundwater. The concentration of vanadium is mostly so low and therefore of low drinking water hygiene significance. The concentrations in the Kabul Basin are also very low (Fig. 3.58).
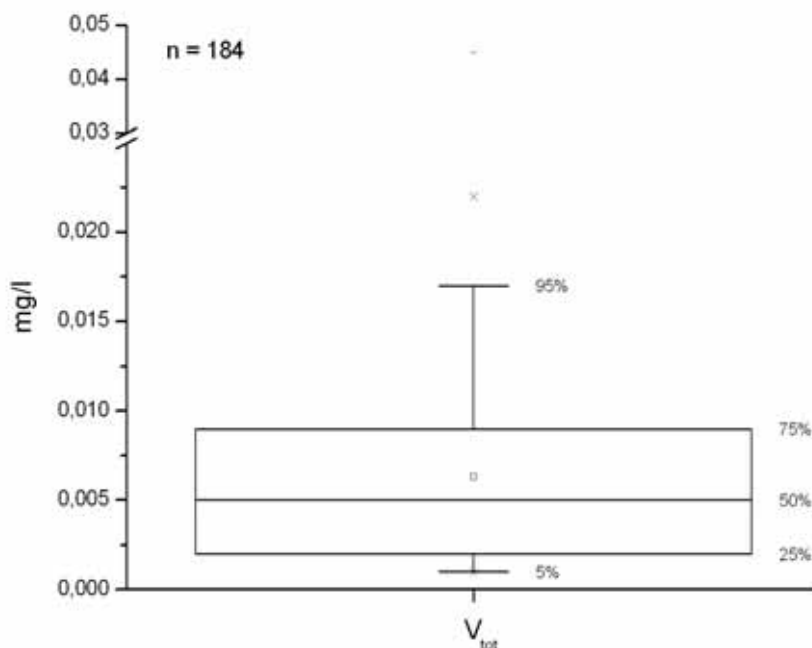
Fig. 3.58: Box-Whisker diagram of vanadium concentrations in the groundwater of the Kabul Basin 2004.

3.6.9 Other heavy metals (lead, cadmium, cobalt)

The lead and cadmium analysis revealed concentrations in all samples below the limit of detection of 0.005 and 0.03 mg/l respectively. In the case of cobalt, one sample had a value of 0.006 mg/l - which does not represent any drinking water hygiene problem. All of the other samples lay below the limit of detection of 0.005 mg/l.

3.7 Microbiology

3.7.1 Introduction

Active soils can contain several billion (10^9) micro-organisms per gram of solid material. Uncontaminated aquifers still contain on average 10^7 micro-organisms per gram solid matter. Most of the organisms in groundwater are prokaryotes (bacteria) without cell nuclei. Viruses can also live in groundwater. Because they are incapable of metabolising and reproducing on their own, they always require a host (obligatory parasite). Hosts in groundwater are predominantly bacteria (bacteriophages). Because the direct detection of viruses in water is extremely complicated, the presence of a large number of bacteria is usually taken as an indirect indication of the presence of viruses. Flow processes mean that a small number of micro-organisms is constantly transported by the groundwater which means that the groundwater, is not sterile per se. Most of the naturally occurring micro-organisms in the groundwater regime can neither survive in water exposed to the air nor are they pathogenic - they are neither transmittable to humans nor capable of causing diseases.

Pathogens, i.e. pathogenic bacteria and viruses do, however, frequently penetrate groundwater as a result of anthropogenic influences, e.g. immissions of faeces, sewage and toxins. Most of the diseases caused by contaminated groundwater are attributable to the input of micro-organisms. Epidemics which can spread via the sewage-drinking water path include typhus, paratyphus, cholera and dysentery. A basic requirement for groundwater hygiene is therefore to protect the groundwater from biological immissions. The bacterial contamination of aquifers almost always concerns faecal contamination (human and animal faeces). The most important intestinal inhabitant of warm-blooded creatures is the bacterium "*Escherichia Coli*". Unlike other coliform bacteria, this bacterium can only multiply within the intestines of its host. This bacterium has a limited lifetime outside of its natural habitat. Periods of 40 - 60 days underground are usually enough to remove the germs affecting drinking water hygiene. This period can, however, be longer in very permeable aquifers.

Immersion tests (Paddle tester manufactured by HACH) were conducted to detect aerobic and coliform bacteria in the water of the Kabul Basin. These tests have nutrient surfaces which are immersed in the liquid being analysed, closed and then incubated at a temperature of 37 °C for approx. 36 hours. If bacteria are present, they begin to grow during this incubation period and are detected by the formation of coloured colonies the size of pin heads. The larger the number of colonies, the higher the number of bacteria per sample. The number can then be determined semi-quantitatively by comparing the number of colonies with comparison diagrams (Fig. 3.59). Unfortunately, there were major problems in practice in identifying colonies and counting which means that the results are not as accurate as required. There seems to be a general underestimation of the level of contamination. It is

important to remember that the microbiological analysis of water is not a trivial matter and that the tests used by the USGS and BGR only allow an initial screening of the bacterial contamination.

The comparative diagrams in Fig. 3.59 illustrate the evaluation of incubated test strips. The samples can be assigned to a contamination class depending on the semi-quantitatively determined number of bacterial colonies.

very low	low	moderate	high	very high

(colony forming units (CFU)/ml)

| 100 (10^2) | 1000 (10^3) | 10,000 (10^4) | 100,000 (10^5) | 1,000,000 (10^6) | 10,000,000 (10^7) |
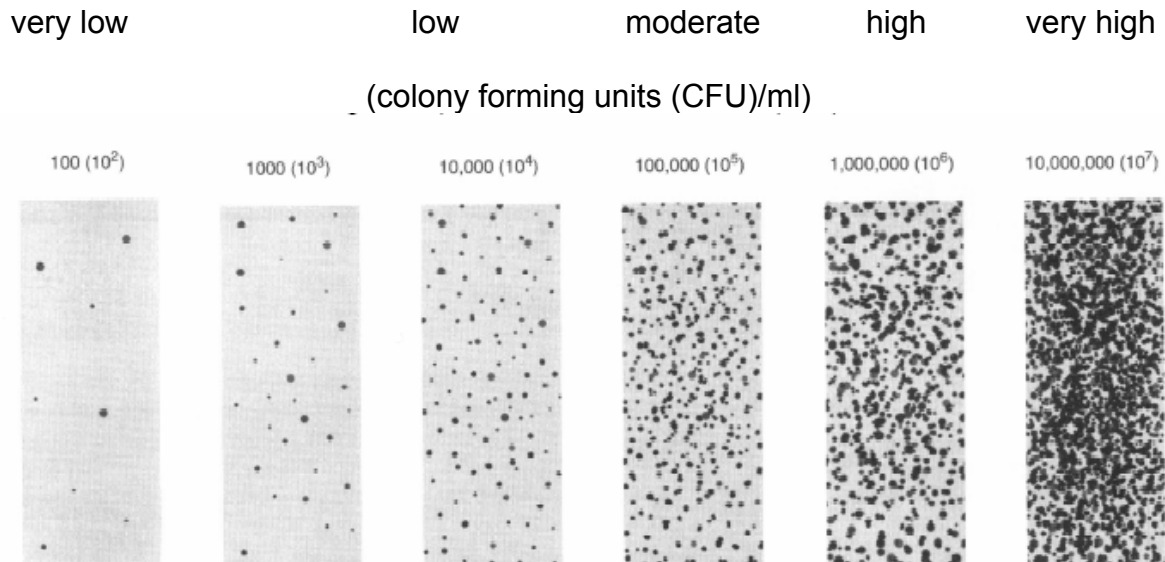
Fig. 3.59: Comparative diagrams for the semi-quantitative evaluation of immersion tests (Paddle tests) manufactured by HACH (CFU = colony forming unit), figure from the operating instructions

3.7.2 Total number of aerobic bacteria

The total number of aerobic bacteria counts the number of bacteria living in an oxygenated environment. Because of the weak oxidising redox environment, the presence of such micro-organisms is expected in the Kabul Basin waters (→ 3.4.1, 3.4.2). It was therefore not necessary to determine the presence of sulphate-reducing bacteria (SRB) or iron oxide reducing bacteria.

The investigation revealed that around 55 % of the analysed wells had significant bacterial contamination (Fig. 3.60). The absence of an effective sewer network is responsible for the presence of various aerobic bacteria in the water because the sewage represents an almost unlimited source of nutrition for the bacteria. Even though the toxicity of these bacteria is rather low - unlike coliform bacteria - this parameter is a good indicator of the anthropogenic contamination of the groundwater.
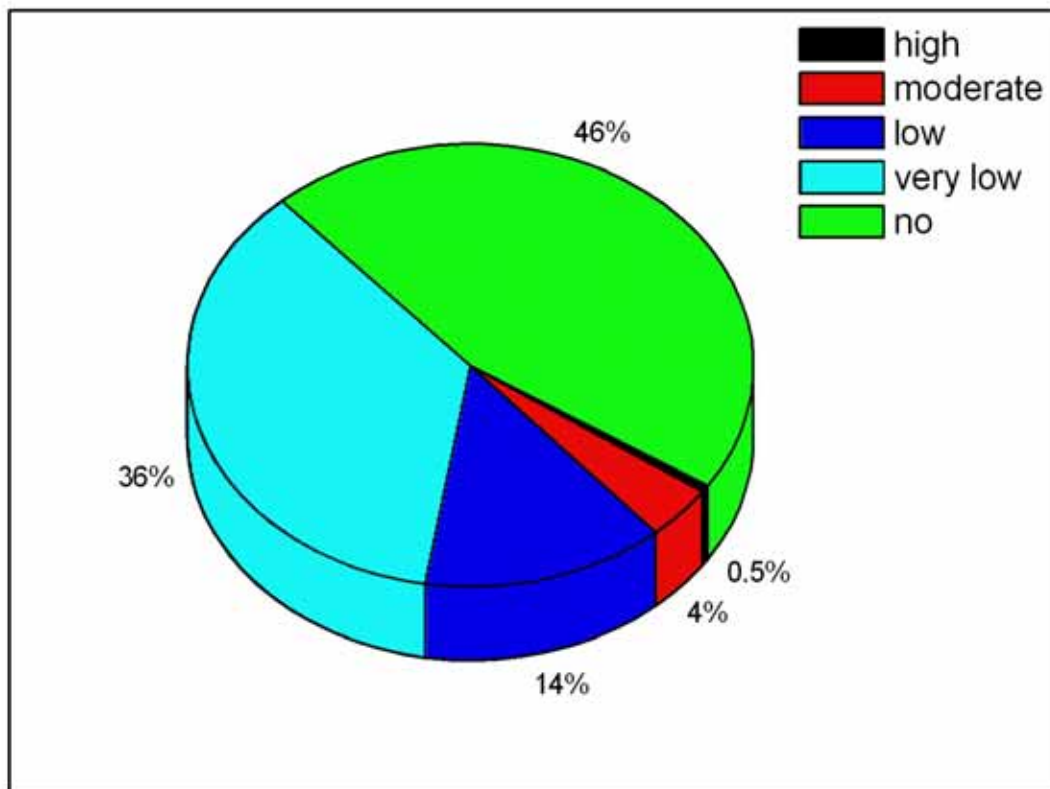
Fig. 3.60: Distribution of contamination classes (as given above) for total number of aerobic bacteria in groundwater of the Kabul Basin (number of samples n = 230) (CFU = colony forming unit).

3.7.3 Coliform bacteria and *Escherischia coli*
The number of coliform bacteria is one of the most important criteria for assessing the microbiological quality of drinking water. The bacteria in question are gram negative, facultatively anaerobic, movable rods which naturally inhabit human and animal intestines. They are normally harmless and an easily identifiable indicator organism for the faecal contamination of drinking water and groundwater. They are facultatively pathogenic and opportunistic, i.e. they can cause illnesses when natural resistance is weakened, for instance in infants and old people. *Escherichia coli* bacteria should therefore not be present in drinking water.

The total number of coliform bacteria is determined in line with the aforementioned semi-quantitative counting method. Fig. 3.61 shows that around 13 % of all investigated wells had significant coliform bacteria contamination and considerably exceeded the WHO limit of 0 CFU/100 ml. The average infant mortality of 146 new born per thousand and around 264 children per thousand up to the age of five is therefore probably largely attributable to the poor drinking water quality in Kabul. The illnesses responsible for this mortality are mainly relatively simple diarrhoea sicknesses.
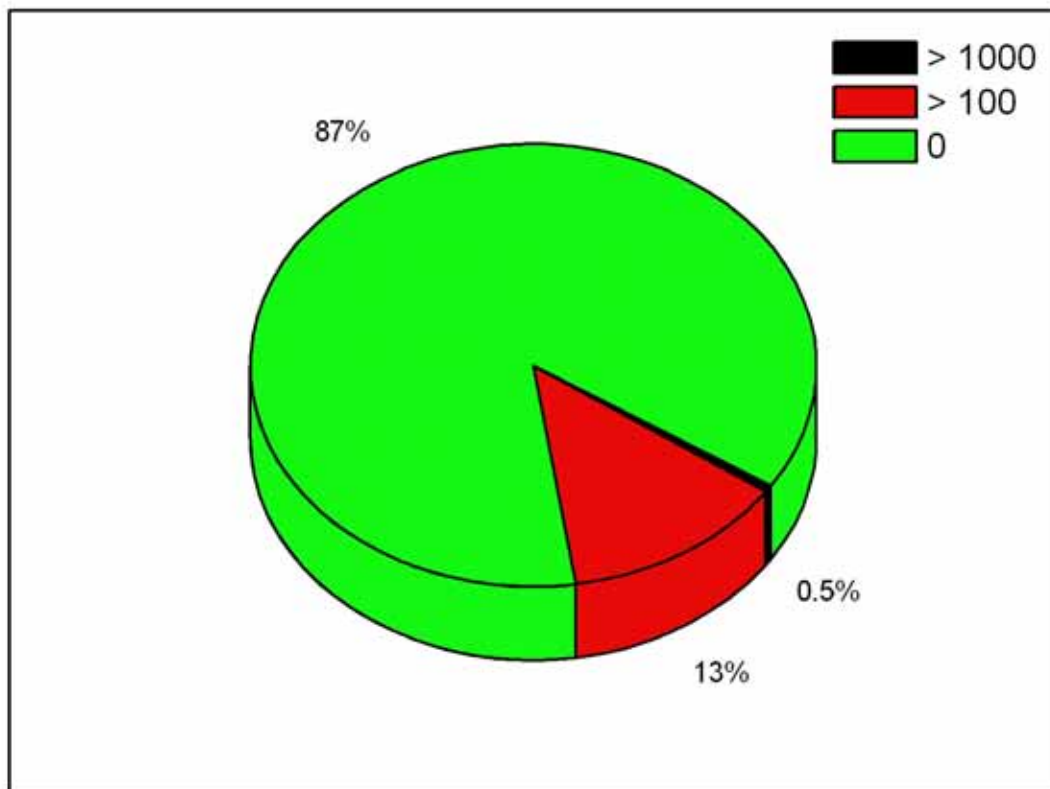
Fig. 3.61: Distribution of contamination classes for the total number of coliform bacteria in groundwater of the Kabul Basin (n = 230) (CFU = colony forming unit).

The high permeability of the main aquifers in the Kabul Basin (see part I) is also a relatively negative aspect from a water hygiene point of view because it enables fast spreading rates coupled with low filtration of the micro-organisms. A crucial factor in retaining the microbiological contamination from the countless drainage pits are the loess and loess-loam beds near the ground surface which have a particularly good filtration capacity because of their fine-grained matrix. Special attention should be given to ensuring that the loess beds are not penetrated when constructing drainage pits and that drainage pits are not dug in areas where there is no loess cover. Care should also be taken to ensure that wells are constructed an adequate distance away from percolation pipes and sewage channels. Attention to the details has often been extremely negligent in the past (Fig. 3.62, 3.63). The same applies to the absence of any properly managed refuse disposal system (Fig. 3.64).

Fig. 3.62: A hand-pumped well extracting shallow groundwater in an urban district of Kabul immediately adjacent to an open sewage channel (photo: TÜNNERMEIER).

Fig. 3.63: A hand-pumped well extracting shallow groundwater in an urban district of Kabul immediately adjacent to an open sewage channel (photo: TÜNNERMEIER).

Fig. 3.64: Unregulated refuse disposal in the urban part of Kabul (photo: TÜNNERMEIER)

The USGS used an analysis method from IDEXX as part of its sample analysis programme which can quantitatively confirm the presence of coliform bacteria and *E.coli* (BROSHEARS et al. 2005). 79 (approx. 73 %) of the 108 analysed samples revealed the presence of coliform bacteria, whilst 25 (approx. 23 %) had *E.coli* (Fig. 3.65). These considerably higher values correlate much better with the proven contamination by sewage than the BGR values which tended to underestimate the bacterial contamination because of difficulties with the analysis method (see above). The USGS study also showed that in addition to wells in the urban areas in Kabul, microbial contamination also affects wells in the surrounding rural area. Many of these cases are probably associated with wells which are inadequately sealed at the top – in the case of shaft wells in particular.
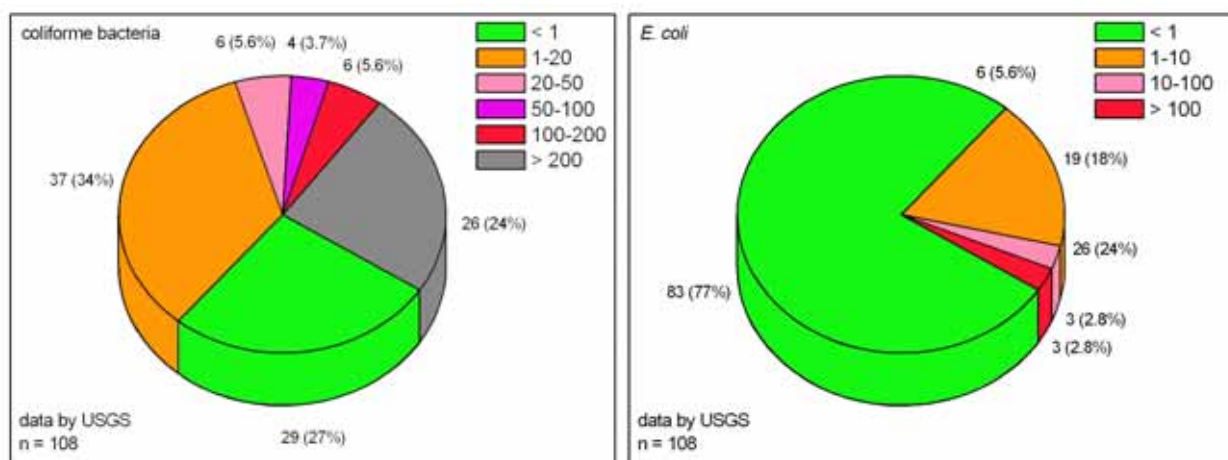
Fig. 3.65: Microbial contamination of Kabul Basin groundwater (after data by BROSHEARS et al. 2005).

The paper by BANKS & SOLDAL (2002) contains a summary of the 1996 results from TIMMINS as part of the "Action contre la faim" programme which investigated 1400 wells in the Kabul Basin to determine the level of faecal bacterial contamination (Tab. 3.2, Fig. 3.66).

Table 3.2: Investigation of the water supply in Kabul with respect to E.coli contamination (n = 1400) in 1996 (data from TIMMINS: quoted in BANKS & SOLDAL 2002).

source	E.coli		
	> 5 per 100 ml	> 100 per 100 ml	> 500 per 100 ml
	% of sources		
wells with hand pumps	45.2	11.1	1.3
open wells	76.5	31.9	4.2
distribution networks	49.0	15.7	1.96

Around 45 % of all wells with hand pumps were contaminated with *E.coli* according to this study. This number is even higher than the USGS finding. The considerably higher contamination of the open shaft wells highlights the importance of proper well sealing for drinking water hygiene. It is also interesting that the contamination of the water supplied via the distribution networks is no better than water from the hand-pumped wells. The pipelines are probably old, ill-maintained and thus leaky.
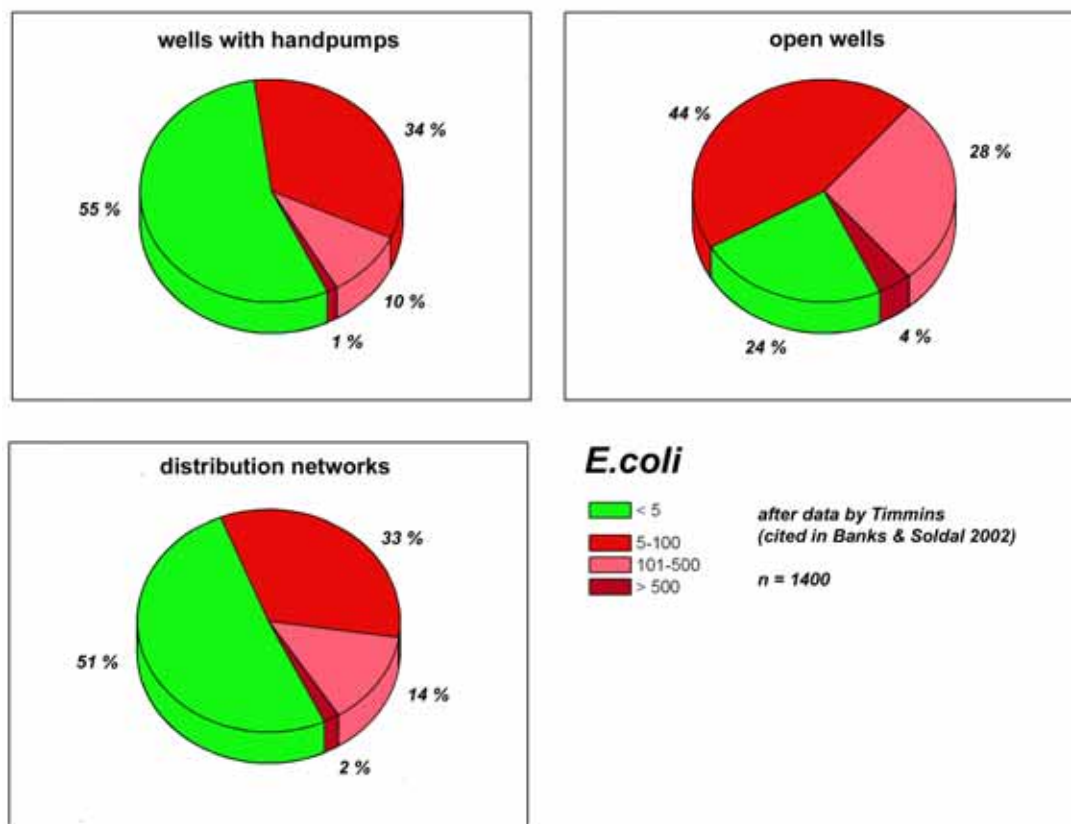
Fig. 3.65: Microbial contamination of Kabul Basin groundwater with *E.coli* (after data from TIMMINS: in BANKS & SOLDAL 2002).

4. Overall interpretation

4.1 Water types

PIPER diagrams are particularly useful for comparing large numbers of water samples because they enable several parameters to be shown at the same time. Fig. 4.1 basically shows a development trend with two end members: a slightly mineralised "natural" $CaHCO_3$ water and a highly mineralised "polluted" $NaClSO_4$ water. Between them lies a very dense band in which the significance of calcium gives way very strongly to magnesium, and where there is an increase in chloride and sulphate. Processes which can cause this are:

- ion exchange
- precipitation of calcite cement in aquifers → relative Mg enrichment
- anthropogenic Mg immissions
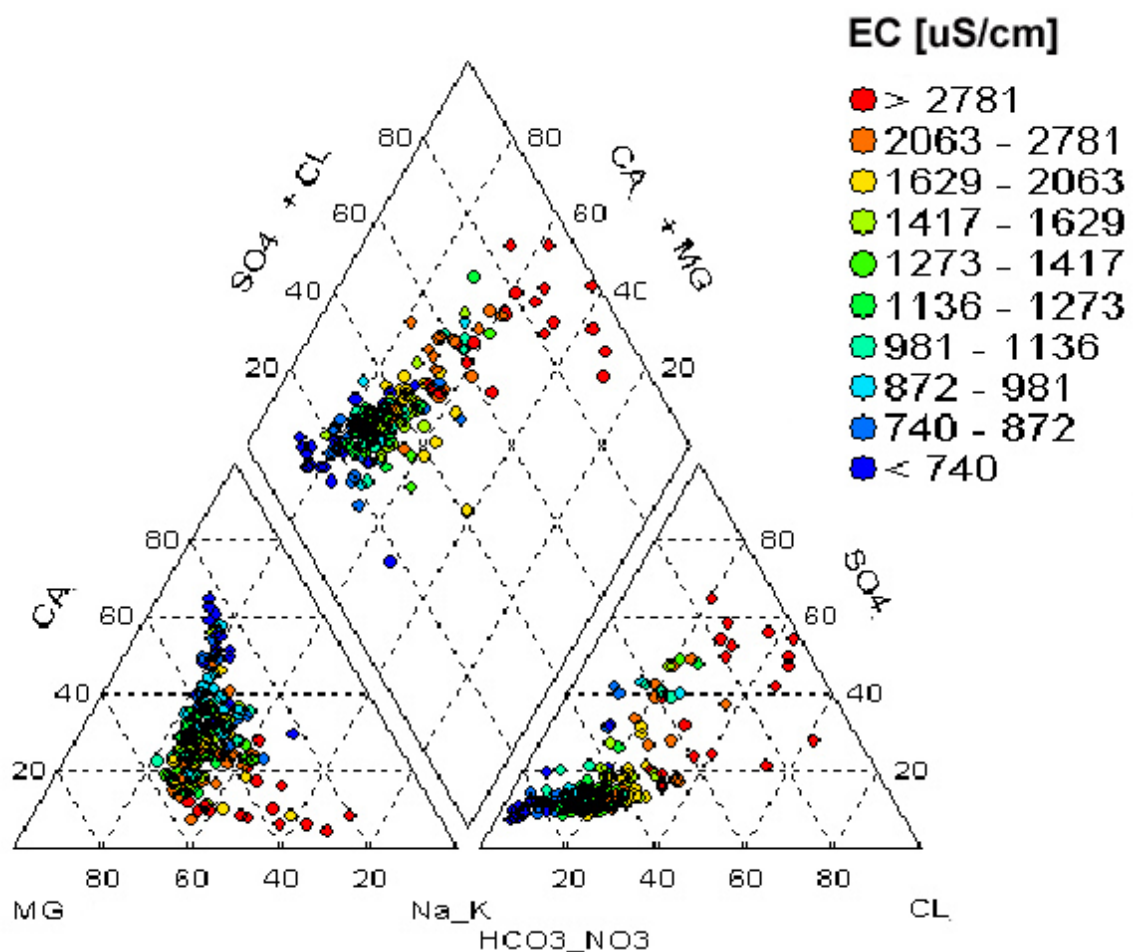
Fig. 4.1: PIPER diagram of groundwater samples from the Kabul Basin 2004. Samples coloured according to specific electrical conductivity (EC) in µS/cm.

The special position of the highly conducting sodium-enriched samples (e.g. the trend in the cation triangle) indicates that these have their own genesis history. This appears to be a sensible hypothesis given their spatial restriction to the dried-up swamp to the west of the airport.

4.2 Comparison with historical water quality data

A comparison of the results of water samples analysed in this study with historical water quality data reveals how the situation has changed over time. However, there is no data at all for the 1979 to 2002 period because of the lengthy war and the civil war.

The data available consisted of hydrochemical maps of the Kabul Basin from GREBE et al. (1966) prepared as part of the "German Geological Mission in Afghanistan". The samples were analysed in the laboratory of the Geological Survey in Kabul which is where the original data were also archived (TREDER, BGR, pers. comm.). Analysis was carried out for chloride, sulphate, total hardness (°dH), carbonate hardness (°dH), magnesium (hardness) (°dH) and calcium (hardness) (°dH). The investigation at that time included at 27 Karezes (underground water channels), 346 shaft wells (shallow groundwater) and 10 pipe wells (deeper groundwater). The values were presented in maps as bar charts. The precise co-ordinates and numbers of the measuring points were not documented. Because the original data was lost as a result of the war, the values had to be read off from the bar charts using a ruler. This method led to some unavoidable inaccuracies. The median (continuous line in the box) should be the focus of attention when comparing the Box-Whisker diagrams in figures 4.2 to 4.4.

For the calcium, chloride and sulphate parameters presented here, one can deduce a general increase in average concentrations from 1966 to 2004 (Figs. 4.2 to 4.4). This trend is not seen in the case of magnesium where the median actually decreases (Fig. 4.4).
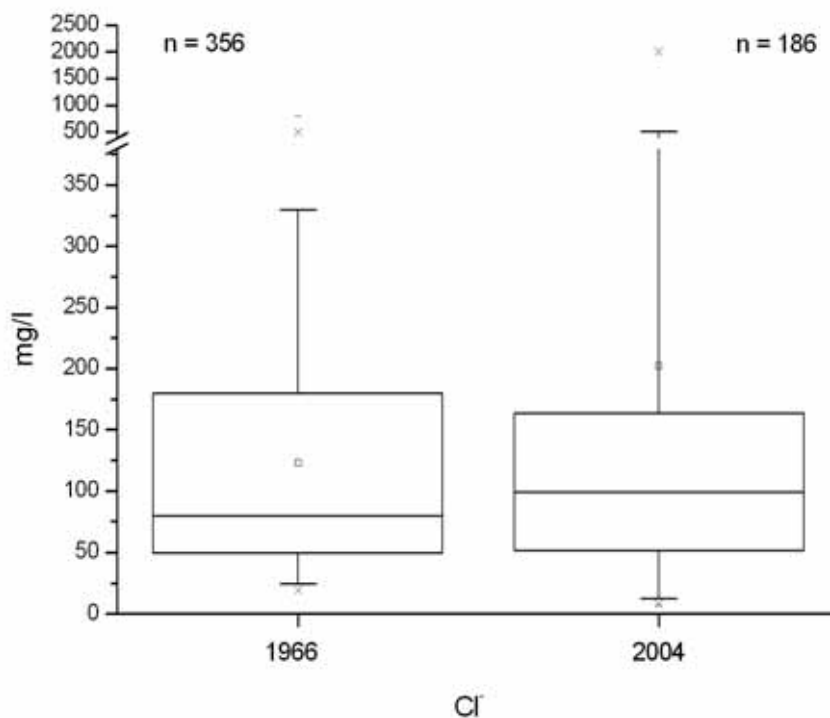
Fig. 4.2: Box-Whisker diagram of chloride concentrations in groundwater of the Kabul Basin 1966 and 2004.
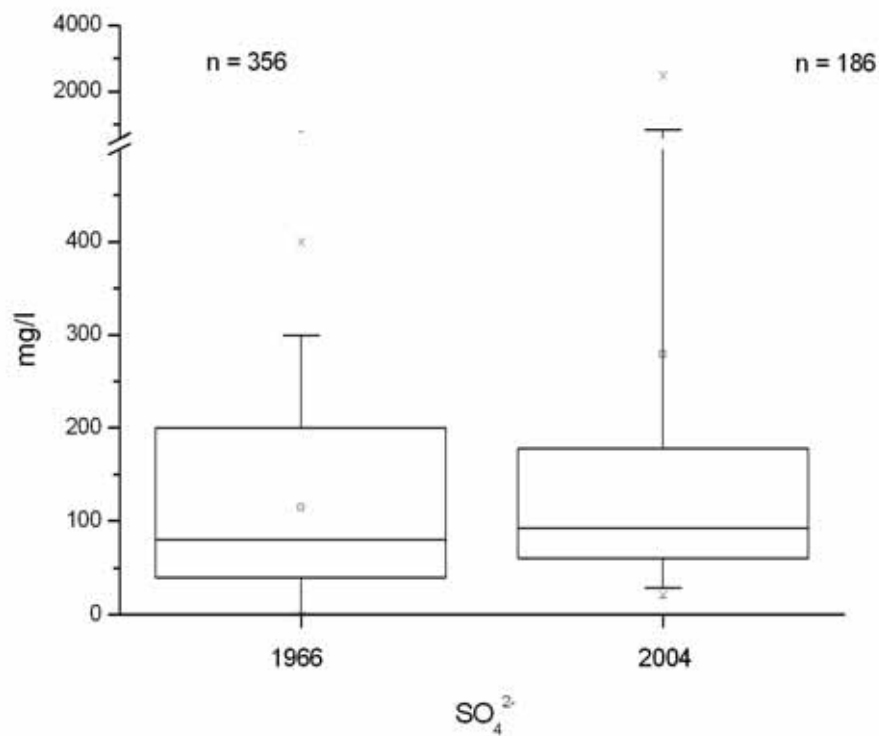
Fig. 4.3: Box-Whisker diagram of sulphate concentrations in the groundwater of the Kabul Basin 1966 and 2004.
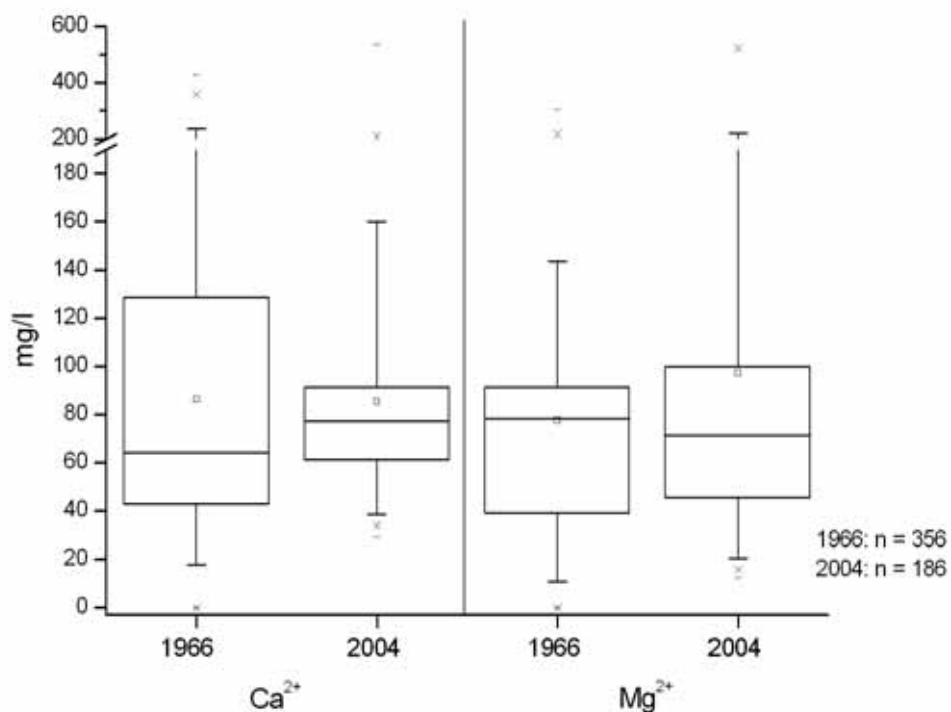
Fig. 4.4: Box-Whisker diagram of the calcium and magnesium concentrations of in the groundwater of the Kabul Basin 1966 and 2004.

Other summary interpretations of the analysis of groundwater in the Logar and Kabul aquifers are contained in BÖCKH (1971). The raw data and information on the location of the wells is unfortunately not available. The results are presented in table 4.1. There are apparently no analysis data on the Paghman aquifer. The results of the two aquifers are very similar and can therefore be interpreted jointly here.

Table 4.1: Hydrochemical parameters of the Logar and Kabul aquifers based on Russian analysis 1962/63 (BÖCKH 1971)

Constituents [mg/l] and °dH	Logar aquifer[1]	Kabul aquifer[2]
Dry residue	470-664	332-540
Calcium	24-36	38,1-68,7
Magnesium	56-85	25,9-52,0
Sodium (incl. potassium)	46-106	32,0-71,8
Hydrogen carbonate	336-457	280,7-421,0
Sulphate	54-127	25,5-76,5
Chloride	53-87	28,9-58,5
Total hardness (°dH)	5,8-7,8	4,6-7,1
Carbonate hardness (°dH)	5,8-7,5	-
Ammonium	0-0,8	0-0,2
Nitrite	0-0,1	0-0,01(?)
Nitrate	-	0-1,0

[1] 18 samples from 4 Soviet exploration wells
[2] 15 samples from 4 Soviet exploration wells and 2 production wells

PROCTOR & REDFERN INT. LTD. (1972) summarised the hydrochemical data of the Paghman, Logar and Kabul aquifers using the results of a Russian exploration programme (tab. 4.2). It is not clear whether it is the same data, at least in part, as that used by BÖCKH (1971). The raw data is missing.

Table 4.2: Hydrochemical parameters of the Paghman, Logar and Kabul aquifers after data from Russian investigations in 1962/63 (PROCTOR & REDFERN INT. LTD. 1972).

Constituents [mg/l] or °dH	Paghman aquifer[1]	Logar aquifer[2]	Kabul aquifer[3]
pH	all samples between pH 7.0 and 8.5		
TDS[a]	1 sample > 500 mg/l	69 samples > 500 mg/l 7 samples > 1500 mg/l max 4800 mg/l	10 samples > 500 mg/l max 618 mg/l
Calcium	all > 75 mg/l	75 samples < 75 mg/l 3 samples < 200 mg/l	35 samples < 75 mg/l 9 samples <90 mg/l
Magnesium	13 to 58 mg/l	73 samples < 150 mg/l 5 samples > 150 mg/l	38 to 95 mg/l
Sulphate	max 62 mg/l	69 samples < 200 mg/l 2 samples < 400 mg/l 2 samples > 400 mg/l	max 77 mg/l
Chloride	max 18 mg/l	67 samples < 200 mg/l 9 samples < 400 mg/l 2 samples > 400 mg/l	max 54 mg/l
Hardness (°)[b]	3.23 to 7.48	6.06 to 15.23 (25 samples > 10)	4.64 to 9.15
Nitrate	max 12.82 mg/l	max 18.60 mg/l (1 sample 60.11 mg/l)	max 7.51 mg/l
Phenol[c]	not detectable[c]		
Zinc	not detectable[c]		
Lead	not detectable[c]		
Copper	not detectable[c]		
Arsenic	not detectable[c]		
Iron	traces	not detectable[c]	
Fluoride	not detectable[c]		

[1] 20 samples [2] 78 samples [3] 44 samples
[a] Total dissolved solids [b] Conversion factor unknown
[c] Limit of detection unknown

Because of the large number of samples this table enables better differentiation of the aquifers. The Logar aquifer appears to have slightly higher mineralisation in general than the others and even seems to contain highly mineralised water at least in parts. This is limited, however, to shallow shaft wells. The relatively low Ca/Mg ratios are significant in both the investigation programmes.

PROCTOR & REDFERN INT. LTD. (1972) also quoted bacteriological investigations carried out in wells in different aquifers (tab. 4.3). According to the methods used at the time, a titre of > 333 meant that the sample complied with the legal standards in the Soviet Union, whilst lower titres indicated contamination with coliform bacteria.

Table 4.3: Bacteriological parameters of the Paghman, Logar and Kabul aquifers after data from Russian investigations in 1962/1963 (PROCTOR & REDFERN INT. LTD. 1972)

	Paghman aquifer[1]	Logar aquifer[2]	Kabul aquifer[3]
Coliform bacteria	4 wells without any findings (titre > 333) 1 well (BH 32) with findings some of the time (titre 138) 1 well (BH 36) with a finding (titre 129)	5 wells without findings (titre > 333) 1 well (BH 1) with a finding (titre 50)	4 wells without findings (titre > 333) 1 well (BH 2) with findings at times (titre 50 - 100)

[1] 12 samples from 6 wells   [2] 25 samples from 6 wells   [3] 17 samples from 5 wells

Investigations by WHO (in PROCTOR & REDFERN INT. LTD.1972) analysed 21 samples from the upper and lower Kabul Basin resulting in 17 negative findings and 4 positive findings with MPN 1, 2, 4 and 22 per ml (MPN = Most Probable Number).

The results of the past investigations are similar in that they can be compared with the recent data. They differ in part very significantly from the groundwater analysed 2004 by BGR and USGS.

The analysis results of the present day groundwater and the historical data reveal the following significant differences:

- **increase in salt concentration**
- **considerable increase in calcium, increase in magnesium**
- **considerable increase in hardness**
- **considerable increase in nitrate**
- **clear increase in sulphate**
- **raised to clearly raised sodium and chloride concentrations**
- **greater contamination with faecal bacteria.**

These differences can be largely explained by contamination with sewage. The associated processes are discussed in more detail in Chapter 4.6.

The recent and the historical data have the following significant similarities:

- neutral to weak basic pH
- low Ca/Mg ratios
- low iron concentrations
- low (heavy) metal concentrations
- similar ammonium and nitrite concentrations.

This indicates that the redox environment has hardly changed despite the greater contamination with oxygen-depleting sewage. The constant pH reveals that the buffer capacity of the groundwater, and the carbonate content of the aquifer in particular, has been large enough to completely buffer even major immissions of acid arising from nitrification.

Some of the separate analyses also presented by Proctor & Redfern Int. Ltd. (1972) from the 1960s and 1970s show that there were already isolated raised nitrate concentrations in Kabul city of around 50 mg/l, e.g. in well "A" in Shar-I-Nau. This well also showed simultaneous significant contamination with faecal bacteria.

The groundwater salinisation to the west of the airport (north of the Wazirabad district of Kabul) described in chapter 3.2 had already been revealed by investigations carried out in the 1960s (Grebe et al. 1966). This means that periods of drought associated with drying out and salinisation of the swamps must already have taken place more than once in the past. Another salinisation zone was encountered at the time in a low lying area at the confluence of the Kabul and Logar rivers.

Banks & Soldal (2002) include a summary of the 1996 results by Timmins conducted on behalf of "*Action contre la faim*". This investigation looked at 1400 water supply outlets (wells and the distribution network) in the Kabul Basin. The considerable impact of nutrients and faecal bacteria was also revealed by this study (→ 3.43; 3.7.3). 32.5 % of the investigated hand-pumped wells had raised nitrate concentrations (> 45 mg/l) whilst 45.2 % had significant *E.coli* contamination.

4.3 Corrosion and encrustation potential

The quasi-neutral pH, the weakly oxidising redox potential and the hardness-related absence of aggressive carbonic acid are favourable conditions with respect to the corrosion potential of the groundwater. However, the high average chloride and sulphate concentrations could still give rise to some degree of corrosion. This corrosion potential is generally classified as moderate with the exception of the particularly chloride-rich water to the west of the airport (→ 3.5.1).

The precipitation of mineral incrustations from the water in wells, pipes and domestic installations reduces their efficiency and gives rise to high costs for the continuously required cleaning or repair (Houben & Treskatis 2003).

Given the elevated hardness and the positive saturation indices of the Kabul Basin groundwater with respect to solid carbonate phases like calcite and dolomite (→ 3.3.3) it is likely that carbonates will be precipitated (boiler scale) - particularly when water is heated.

The solid sulphates of the alkaline earth ions such as gypsum, anhydrite and baryte form particularly tough incrustations because they are so difficult to remove. Whilst baryte is not expected to play any rule here because of its low concentrations (→ 3.5.7) despite its oversaturation, the gypsum and anhydrite mineral phases do not achieve saturation equilibrium (Fig. 3.29). However, this could be exceeded if the water is heated strongly.

Amorphous silicica could precipitate in water boilers in particular because of the raised silicon concentrations (→ 3.5.5). Precise prognosis is not possible because of the number of potentially dissolved and solid silicon constituents. This potential should, however, be taken into consideration because of the associated particularly hard and tough incrustations.

Ochre incrustation which occurs particularly frequently in Central Europe, i.e. by the precipitation of iron oxides and manganese oxides, is only of minor importance in the Kabul Basin because of the redox conditions and the associated low iron and manganese concentrations ($\rightarrow$ 3.4.1; 3.4.4).

The oxidic redox environment also prevents the formation of metal sulphide incrustations ($\rightarrow$ 3.4.5). This statement is subject to the limitation that our sampling mainly looked at shallow wells. The problem of ochre incrustation/sulphide formation could become acute if deep wells are used to extract water in areas with reducing redox environments. Because of the neutral pH, the formation of aluminium hydroxide incrustations is considered to be very unlikely. Table 4.4 summarises the incrustation potential.

Table 4.4: Encrustation potential of Kabul Basin groundwater.

Incrustation type	Mineral phases	Dissolved concentrations	SI*	In-crustation potential
Carbonate	Calcite	high	> 0	high
	Dolomite	high	> 0	high
Alkaline earth sulphates	Gypsum	high	< 0	low
	Anhydrite	high	< 0	low
	Baryte	very low	(> 0)	low
Ochre incrustation	"Iron oxides"	very low	< 0	very low
	"Manganese oxides"	very low	< 0	very low
Metal sulphides	"FeS"	very low	< 0	very low
	Pyrite	very low	< 0	very low
Aluminium hydroxide	Gibbsite	very low	< 0	very low
Silicification	"SiO$_2$"	moderate to high	> 0	moderate

* SI > 0: water oversaturated with respect to mineral phase, mineral can precipitate
  SI < 0: water undersaturated with respect to mineral phase, mineral can be dissolved further

4.4 Suitability of the groundwater for irrigation

In the past, irrigation water was extracted in the Kabul Basin from the rivers flowing through the basin. This water was diverted into open channels and underground Kanata (known as Karezes in Afghanistan). There is currently no agricultural activity in the Kabul Basin because of the lengthy drought and the associated drying out of the rivers. Replacing this water with groundwater is basically not feasible because of the costs and the relatively low productivity of the wells required and the limited resources.

An important parameter in assessing the suitability of water for irrigation is the ratio of sodium to the total calcium and magnesium expressed as the "sodium adsorption ratio" (SAR) (Fig. 4.5). There is a risk that high sodium concentrations can cause negative changes to the soil structure because of the shrinkage this causes to swelling clay minerals.

The samples of the Kabul Basin reveal that most of the water would not give rise to any or only very minor problems with respect to SAR (Fig. 4.5). This is because of the naturally high calcium and magnesium concentrations (hardness) of most of the samples. However, these concentrations and the high evaporation rates could lead to the build-up of carbonate concretions in the irrigation pipes and the soil (calcrete). However, most of the wells would already cause problems during irrigation as a result of soil salinisation because of their high salt contents, particularly the highly saline waters ($\rightarrow$ 3.2). Treated wastewater would also be problematic.
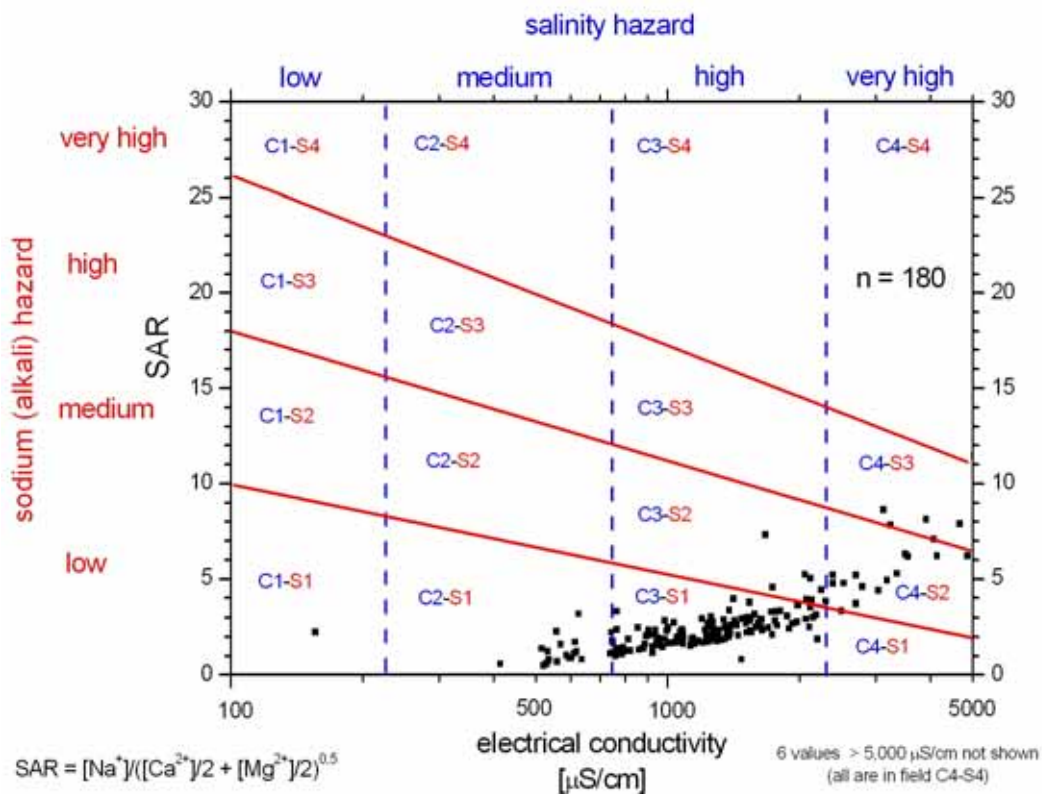
Fig. 4.5: Sodium adsorption ratio (SAR) diagram and salinity of Kabul Basin groundwater 2004. Diagram type after US DEPARTMENT OF AGRICULTURE.

The samples with raised borate concentrations are also expected to have a negative impact on plant growth ($\rightarrow$ 3.5.3; tab. 4.5). Sensitive plants such as beans and avocados can only tolerate 1.2 mg/l borate in irrigation water in the long term (NABLE et al. 1997). This figure is exceeded in approx. 80 % of all of the samples. Plants such as onions, oats, maize and potatoes are able to tolerate levels of 4 - 8 mg/l. Very boron-tolerant plants such as carrots, alfalfa and sugar beet can even cope with high concentrations of up to 16 mg/l (NABLE et al. 1997). The problem will continually get worse as the boron contamination increases in the future as the adsorption capacity of the soil minerals become exhausted and the increasing concentrations restrict the growth of more and more plant types.

Table 4.5: Recommendations for boron concentrations in irrigation water in British Columbia, Canada (http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/boron.html)

Tolerance	Boron in Irrigation Water (mg/L)	Agricultural Crop
Very sensitive	< 0.5	Blackberry
Sensitive	0.5 - 1.0	Peach, cherry, plum, grape, cowpea, onion, garlic, sweet potato, wheat, barley, sunflower, mung bean, sesame, lupin, strawberry, Jerusalem artichoke, kidney bean, lima bean
Moderately sensitive	1.0 - 2.0	Red pepper, pea, carrot, radish, potato, cucumber
Moderately tolerant	2.0 - 4.0	Lettuce, cabbage, celery, turnip, Kentucky bluegrass, oat, corn, artichoke, tobacco, mustard, clover, squash, muskmelon
Tolerant	4.0 - 6.0	Sorghum, tomato, alfalfa, purple vetch, parsley, red beet, sugar beet
Very tolerant	6.0 - 15.0	Asparagus

4.5 Main hydrochemical processes and mass balance analysis

The recent water quality data obtained from this study ($\rightarrow$ 3) allows a reaction sequence to be derived by comparison with the historical quality data ($\rightarrow$ 4.3) which can be used to explain the genesis of the hydrochemistry (Fig. 4.6). Of critical importance here is the sewage which has a massive impact on the natural groundwater quality.

The main constituents of sewage are biomass and salts such as ammonium from the break-down of organic nitrogen compounds (e.g. urea). Biomass primarily arises from faeces (80 %), whilst the nitrogen salts primarily come from urine (90 %).

The first step involves the oxidation of sewage ammonium to nitrate (R 4.1) whilst the biomass becomes mineralised (R 4.2). This depletes the dissolved oxygen and releases acids which in due cause dissolve solid carbonates from the aquifer matrix with a subsequent increase in hardness. Evidence for these reactions includes the low oxygen saturation of the shallow groundwater ($\rightarrow$ 3.4.2) and the absence of ammonium ($\rightarrow$ 3.4.3). Contamination by sewage is not high enough, however, to cause complete oxygen depletion ($\rightarrow$ 3.4). The acid is subsequently buffered by reaction with the solid (calcium) carbonate from the aquifer matrix (R 4.3) which causes a significant increase in the total hardness of the water. There is therefore hardly any change in the pH.

$$NH_4^+ + 2\ O_2 \leftrightarrow NO_3^- + 2\ H^+ + H_2O \qquad\qquad (R\ 4.1)$$
$$"CH_2O" + O_2 \leftrightarrow HCO_3^- + H^+ \qquad\qquad (R\ 4.2)$$
$$H^+ + CaCO_3 \leftrightarrow HCO_3^- + Ca^{2+} \qquad\qquad (R\ 4.3)$$
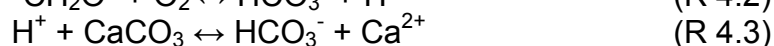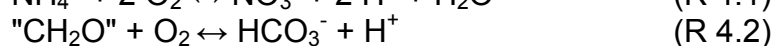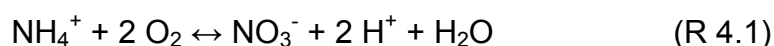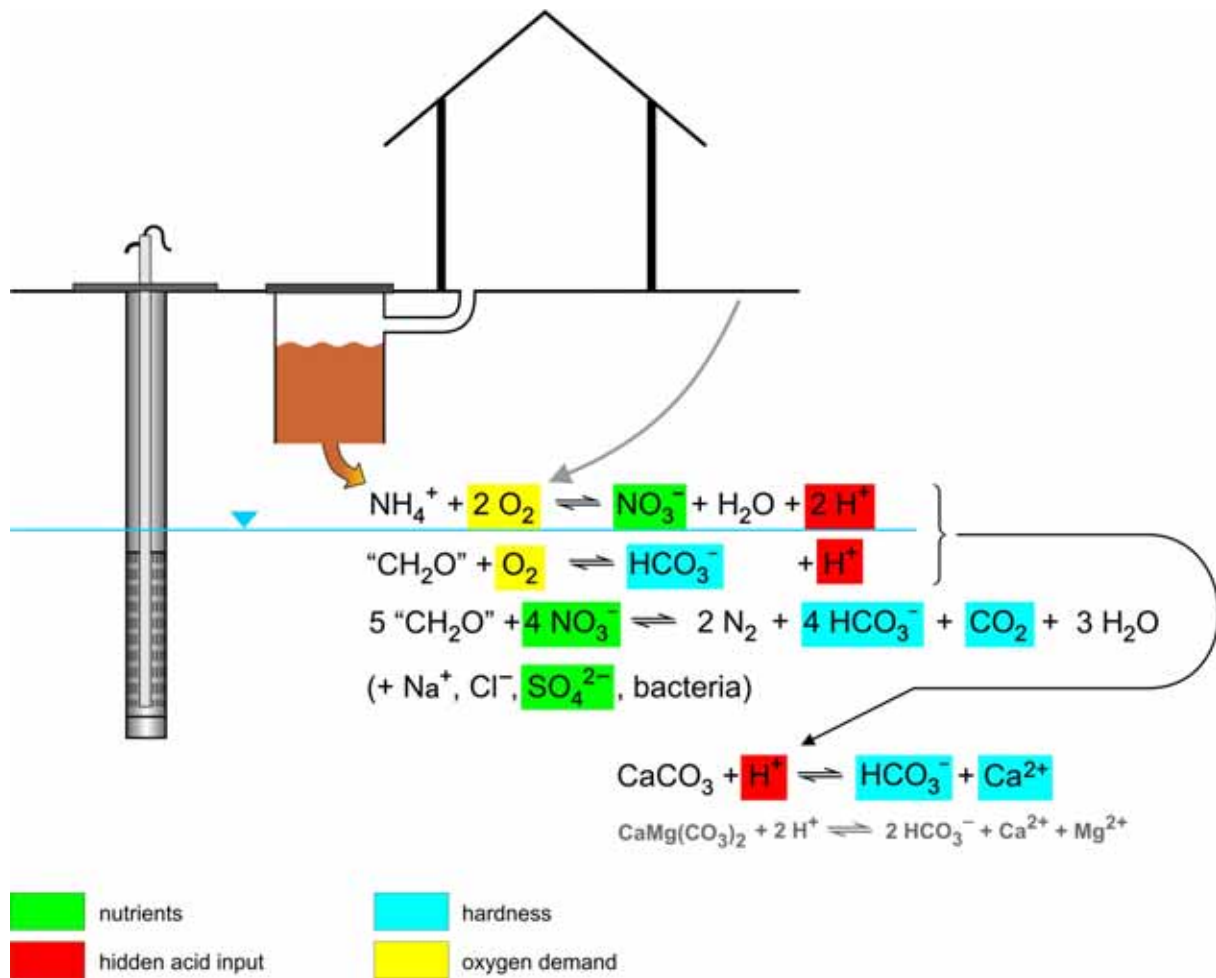
Fig. 4.6: Simplified diagram showing the anthropogenic impact on groundwater quality associated with the chemical processes arising from sewage contamination in Kabul city.

Humans excrete around 14 g (= 1.0 mol) nitrogen per day in urine in the form of 30 g urea (CH_4N_2O). Complete nitrification of the resulting ammonium according to (R 4.1) gives rise to approx. 62 g nitrate and 2 mol acid. Buffering the latter requires 2 mol calcium carbonate in accordance with (R 4.3) - which corresponds to a mass of around 200 g! Given this very high value one also needs to take into consideration the fact that a small amount of nitrogen at least in the drainage pit is not converted into ammonium but into gaseous ammonia. This escapes into the atmosphere. In addition, humans also excrete 30 - 60 mmol/l sulphate every day in their urine. This corresponds to 2.88 - 5.76 g.

These figures can be used to balance the emmissions of the current population of 3.5 million people. The fact that the inhabitants include very large numbers of children needs to be taken into consideration because they excrete smaller amounts of minerals because of their lower body weight. If one assumes daily excretion of 20 g urea (= 41 g nitrate) and 3 g sulphate, the total immissions are therefore

52,400 t/a nitrate
3,800 t/a sulphate

Assuming a total static groundwater volume of 200,000,000 m³ in the Kabul basin (see part I of this study) the nitrate input described above would result in an annual increase in nitrate concentrations by 210 mg/l. This is of course not the case as the actual concentrations are far less ($\rightarrow$ 3.4.3). Substantial parts of the nitrogen must therefore be lost either through runoff in surface waters or by denitrification reactions.

It is not currently possible to estimate the degree to which processes which break down nitrate reduce the nitrate immissions. The most probable denitrification pathway is heterotrophic denitrification by organic matter (R 4.4).

$$5 \text{ "CH}_2\text{O"} + 4 \text{ NO}_3^- \leftrightarrow 2 \text{ N}_2 + 4 \text{ HCO}_3^- + \text{CO}_2 + 3 \text{ H}_2\text{O} \qquad \text{(R 4.4)}$$

This process will only commence after most of the oxygen has been consumed. Reaction R 4.4 could explain the removal of larger amounts of dissolved organic carbon from the water by degradation of the faecal biomass. Since organic carbon is converted to inorganic heterotrophic denitrification this would at the same time lead to extra hardening of the water (R 4.4). Nitrate nitrogen is transformed into nitrogen gas (N_2) by this process which largely escapes to soil gas and finally the atmosphere. Usually the amount of biomass (faecal biomass and kitchen slops) is higher than the amount of organic carbon consumed by heterotrophic denitrification. Therefore some organic carbon is probably released into soil and/or groundwater where it consumes oxygen. The overall processes depicted in figure 4.6 closely resembles the processes occurring in sewage treatment plants.

It should be possible to confirm the acid buffering effect of the carbonate minerals by correlating between the hardness formers calcium and magnesium and the nitrate. This effect is clearly revealed in figure 4.7. The reasonably good correlation with calcium and magnesium indicates that magnesium compounds (e.g. dolomite) are also involved in the buffering process. And because the concentration of magnesium is often even higher than that of calcium ($\rightarrow$ 3.3.2), the acid-related weathering of magnesium silicates is also possible as part of the buffering process.
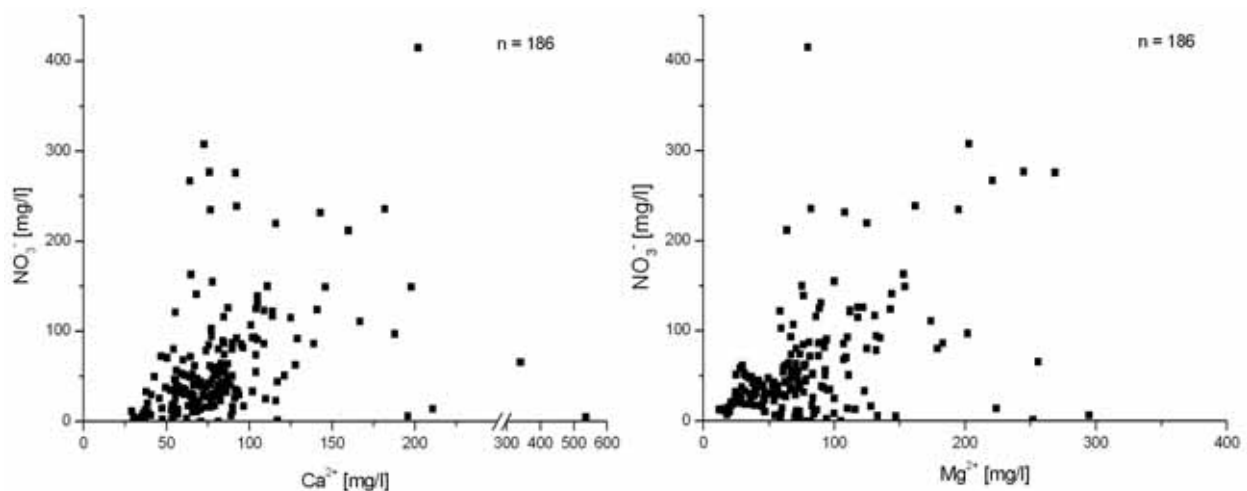
Fig. 4.7: Correlation of calcium and magnesium concentrations against nitrate in the groundwater of the Kabul Basin 2004.

The reactions described here can already take place in the unsaturated soil zone and/or in shallow groundwaters. The sewage also adds additional salt (sodium,

chloride, sulphate) and bacteria to the groundwater and promotes the growth of the bacteria by the large supply of nutrients.

Assessing the significance of contamination in the Kabul Basin, it is prudent to look at the main material flows qualitatively at least (Fig. 4.8). The closed system of the Kabul Basin as an intra-montane basin, allows such a balance to be delimited. The Logar, Kabul and Paghman rivers only transport a minor amount of mineralisation with them when they enter the basin. In addition to seepage from the rivers, there is some infiltration at the foot of slopes. The mineralisation of the recharged water increases slightly more as a result of water-rock-interactions within the aquifer. The strong increase in the number of inhabitants in Kabul gives rise to a considerable increase in the material load because of the disposal of sewage directly into the groundwater. The reaction of the sewage with the soil and the aquifers also cause additional changes to the water quality.
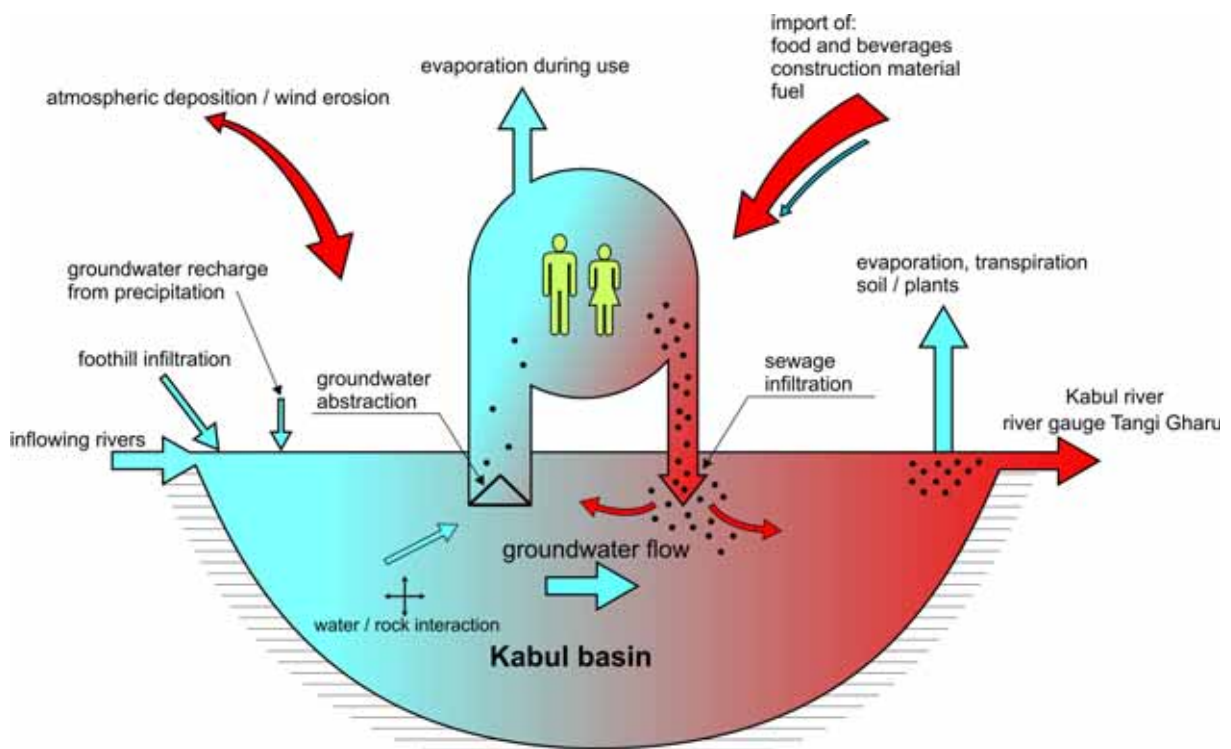
Fig. 4.8: Schematic diagram of material flows in Kabul Basin groundwater

The enrichment in the salt load is exacerbated further by the strong evaporation and the import of food, drinks, construction materials and fuel and the associated net mineral imports. The only quantitatively significant discharge route for immissions is the Kabul river - and/or the groundwater - at the basin outlet at Tangi Gharu. Discharge is currently very low because of the lengthy drought which concentrates mineralisation further. Inhabitants also continue to extract groundwater and infiltrate only smaller amounts back because of the evaporation losses. This lowers the water levels and reduces the amount of stored water. Because most of the infiltrating water is sewage, this must give rise to a strong accumulation of salts particularly when they are recycled many times.

The major contamination of the Kabul Basin groundwater with dissolved minerals can naturally only be reduced by a wet period lasting several years which flushes out the minerals from the aquifer. The mean residence time of groundwater in the basin - which is yet unknown - needs to be considered in this regard.

The problem can be ameliorated by implementing urban planning and/or technical measures:

- regulated urban planning
- regulated refuse disposal/collection in the urban area and proper disposal
- centralised and/or decentralised water supply (with treatment)
- centralised and/or decentralised sewage treatment
- sale of water from tankers.

Because of the size of the city, the frequent uncontrolled building, and the wide-spread poverty, it is unrealistic to upgrade centralised water supply and disposal at a large scale. Decentralised solutions with the supply of several blocks from deep wells and sewage disposal with small downstream treatment plants are feasible in some urban districts at least. Given the probability of the repeated occurrence of droughts, a long-term solution worthy of consideration should be long-distance water supply from rainy areas in the north (e.g. from Salang).

Short-term measures will only have a limited effect. These include shutting down the particularly strongly contaminated wells. Attention should also be given to the proper construction of drainage pits. They should never be constructed in the immediate vicinity of wells or in areas where there is no loess cover. They should also never be dug so deeply that they penetrate the base of the loess cover.

4.6 Comparison with hydrochemical data from the rural area surrounding Kabul

Data from the USGS campaign (BROSHEARS et al. 2005) has now made hydrochemical analysis data available on the rural area surrounding Kabul. Comparisons are necessary because these areas have basically the same geology as the urban areas but have different housing densities and land use. In simple terms, the rural areas have quasi-geogenic groundwater qualities because the sparse habitation and low levels of fertiliser use mean that they have suffered virtually no anthropogenic impact. Only samples which lay outside of the urban area investigated by BGR were selected from the USGS data set (n = 62). Figure 4.9 summarises the difference between the urban areas (BGR samples) and the rural surroundings (selected USGS samples).

The findings resemble the comparisons with the historical water quality data ($\rightarrow$ 4.2). This reveals that the concentration of the sewage-related contaminants nitrate and sulphate are almost twice as high in the urban area as in the rural areas. This is also associated with major differences in the concentrations of the hardness-forming ions calcium, magnesium and hydrogen carbonate which are much higher in the urban areas. This provides excellent confirmation of the theory presented in the previous Chapter 4.5 (and in Fig. 4.6) which proposes that the acid arising from the mineralisation of urea and the organic matter in the sewage is buffered by the

reaction with carbonates. Magnesium also plays an extraordinarily important role here as well.
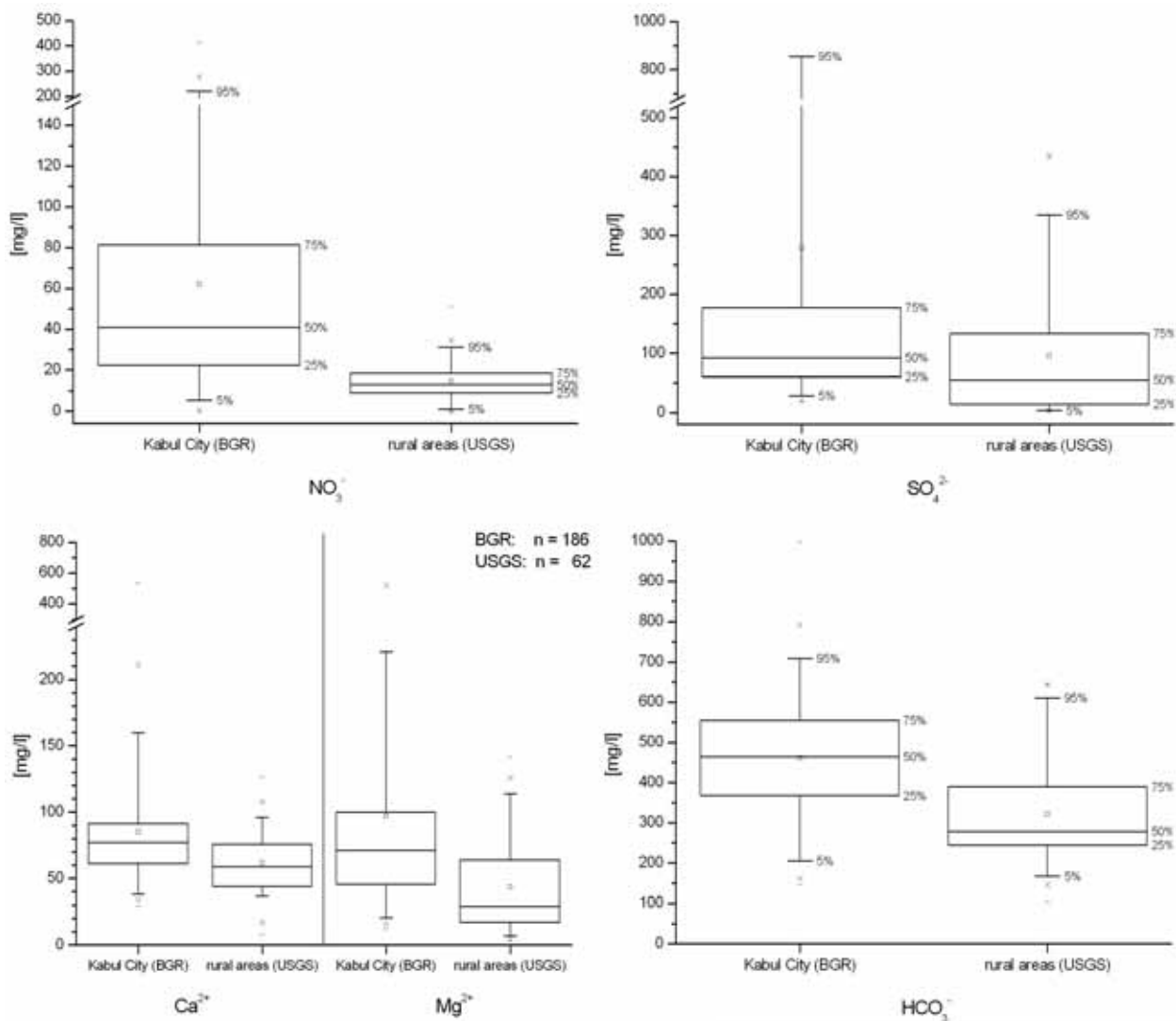
Fig. 4.9: Box-Whisker diagram of concentrations of nitrate, sulphate, calcium/magnesium and hydrogen carbonate in groundwater of the Kabul Basin 2004 in Kabul city (BGR data set) and the surrounding rural areas (USGS data by BROSHEARS et al. 2005).

4.7 Water chemistry of surface waters

The sampling campaign encountered the rivers at a very low runoff stage (see chapter 4 of part I of this study). While the rivers were full during April and May due to the first significant snow melt after six years, the flow had turned to a trickle at the time of sampling. The main chemical data of the samples are listed in tables 4.6 and 4.7. The full data set can be found in appendix 12.

The samples from inside and downstream of Kabul city show impacts of waste water influence. Salinities are usually on the high end, often due to elevated NaCl-and sulphate concentrations. Especially the Paghman river had essentially degraded to a

stinking cloaca of the surrounding quarters, carrying extremely high concentrations of ammonia and phosphate which more resemble wastewater than river water. Compared to groundwater, pH and phosphate concentrations are significantly higher in river water while borate is on the higher end. Interestingly, the samples from the Logar river show high borate concentrations although being far from the densely populated city.

Tab. 4.6: Main hydrochemical parameters of river water in Kabul, summer 2005

	pH	EC	K	Na	Cl	Mg	Ca	SO4	NO3	NH4	PO4	BO2	NPOC
	-	µS/cm						mg/l					
Kabul river at Cp. Warehouse	9,0	2200	9,6	248	263	137	39,7	312	4,7	0,02	2,30	9,06	4,3
Kabul river at Artang bridge	7,7	919	7,1	62,7	69,5	48,6	66,9	61,8	27,7	< dl	1,30	3,01	86,7
Paghman river at Darulaman	8,2	3000	55,3	344	248	53,3	101	na	na	114	31,6	2,89	48,4
Logar river at Bagrame 1	8,6	1500	6,7	114	114	116	41,2	203	0,2	0,02	0,24	5,61	3,0
Logar river Bagrame 2	8,6	1470	6,8	117	119	119	39,6	207	0,6	0,09	0,22	5,87	2,6

na = not analysed   NPOC = non-purgeable organic carbon   <dl = below detection limit

The Logar river has a strikingly low Ca/Mg ratio which can probably be related to the weathering of magnesium-rich minerals present in the ultramafic ophiolithe rocks in its upper catchment area (→ 3.3.2). This phenomenon is less pronounced in the Kabul river and absent in the Paghman area (aquifer, spring, Kharga lake; Tab. 4.X, 4.Y) and the Karez at the right flank of the Logar valley.

The samples presented in table 4.7 come from comparably pristine environments located far from dense human settlements. They may thus be considered as examples of the geogenic chemical background. Accordingly, the salinities are very low and pollution indicators, more or less absent. The low borate concentrations are probably related to the short subsurface residence time of the waters which prevents enrichment through evaporation.

Tab. 4.7: Main hydrochemical parameters of spring and lake water in Kabul, summer 2005

	pH	EC	K	Na	Cl	Mg	Ca	SO4	NO3	NH4	PO4	BO2	NPOC
	-	µS/cm						mg/l					
Paghman spring	6,7	173	1,0	6,7	5,0	5,65	20,7	12,0	5,0	<dl	0,02	0,26	0,8
Karez Amin	8,0	327	3,2	9,7	4,8	8,68	47,1	23,3	15,2	<dl	0,08	0,35	1,0
Kharga Lake	7,1	162	1,4	5,0	3,2	4,38	22,5	9,0	4,9	0,01	0,02	0,17	1,9

<dl = below detection limit   NPOC = non-purgeable organic carbon

4.8 Stable and radiogenic isotopes in precipitation

The GNIP database (Global Network of Isotopes in Precipitation) of the IAEA (International Atomic Energy Agency) contains a fairly coherent isotope data set of precipitation water in Kabul (Karizimir) from 1962 to 1989 (with a hiatus from 1976 to 1981). The data are not restricted and may be downloaded free of charge from the IAEA homepage (http://isohis.iaea.org/).

The stable isotope data for hydrogen (deuterium, ^2H) and oxygen (^{18}O) are sufficient to construct a linear correlation between the two parameters, a so-called meteoric water line (MWL) specific for the Kabul basin (Fig. 4.10). This line is reasonably close to the global MWL defined by CRAIG (1961, cited in CLARK & FRITZ 1997) with

$$\delta^2H = 8 * \delta^{18}O + 10 \qquad [R\ 4.5]$$

Both values are expressed as permil difference from a reference (here: Standard Mean Ocean Water, SMOW) using the delta (δ) notation, e.g. for oxygen:

$$\delta^{18}O_{sample}[‰] = \left(\frac{(^{18}O/^{16}O)_{sample}}{(^{18}O/^{16}O)_{reference}} - 1 \right) \cdot 1000$$

The range of oxygen and hydrogen isotope values depicted in figure 4.10 is typical for precipitation colder regions at low latitudes. The average values of the stable oxygen isotope ratio (^{18}O) can be used to calculate the mean annual air temperatures T_{annual} after DANSGAARD (1964, cited in CLARK & FRITZ 1997) according to:

$$\delta^{18}O = 0.695 * T_{annual} - 13.6 \qquad [R\ 4.6]$$
$$\delta^2H = 5.6 * T_{annual} - 100 \qquad [R\ 4.7]$$

With a median value of $^{18}O = -6.0$ ‰ for the Kabul precipitation from 1962 to 1989 (Fig. 4.11), we obtain an average air temperature of 10.9° C. This compares very well with the average of 10.8° C derived from observed climate data (1957-1977, see part I of this study, Fig. 3.6). The value computed for deuterium with a median $^2H = -28.25$ ‰ yields 12.8° C which points in the same direction.

It is expected that the heavy evaporation rates in the Kabul basin should lead to a certain offset of groundwater isotopy from the MWL shown in figure 4.10.

Regular variations of deuterium and ^{18}O (Fig. 4.12), especially visible in the 1980s, show the influence of the seasonal climate development on the composition of the isotopes. The amount of heavier isotopes increases with increasing temperatures. These variations would be helpful to assess groundwater recharge conditions and residence times when compared to - so far missing - groundwater isotope data.

The input curve of radiogenic tritium (^3H) shown in figure 4.13 follows a classic pattern influenced by the atmospheric atom bomb tests in the 1950s and 1960s. Very high tritium counts in the 1960s reflect the large tritium output of the nuclear bombs. The test-ban and radioactive decay ($t_{1/2} = 12.7$ years) have then led to a pronounced decline of tritium. Present-day rainwater and probably also groundwater recharge will

have low tritium counts. Age dating with tritium will therefore probably only be feasible for deeper and thus older groundwaters. We expect the residence times of groundwater in the Kabul aquifers to be rather low due to the high permeabilities, the strong aquifer flushing by the river exfiltration after the snow melt and high extraction rates.

Comparing these precipitation isotope data to groundwater and surface water isotopic data - which are so far not available - would be very helpful to elucidate several interesting hydrological features of the Kabul basin. This includes:

- groundwater recharge conditions
- mean residence time of groundwater
- influence of evaporation on groundwater
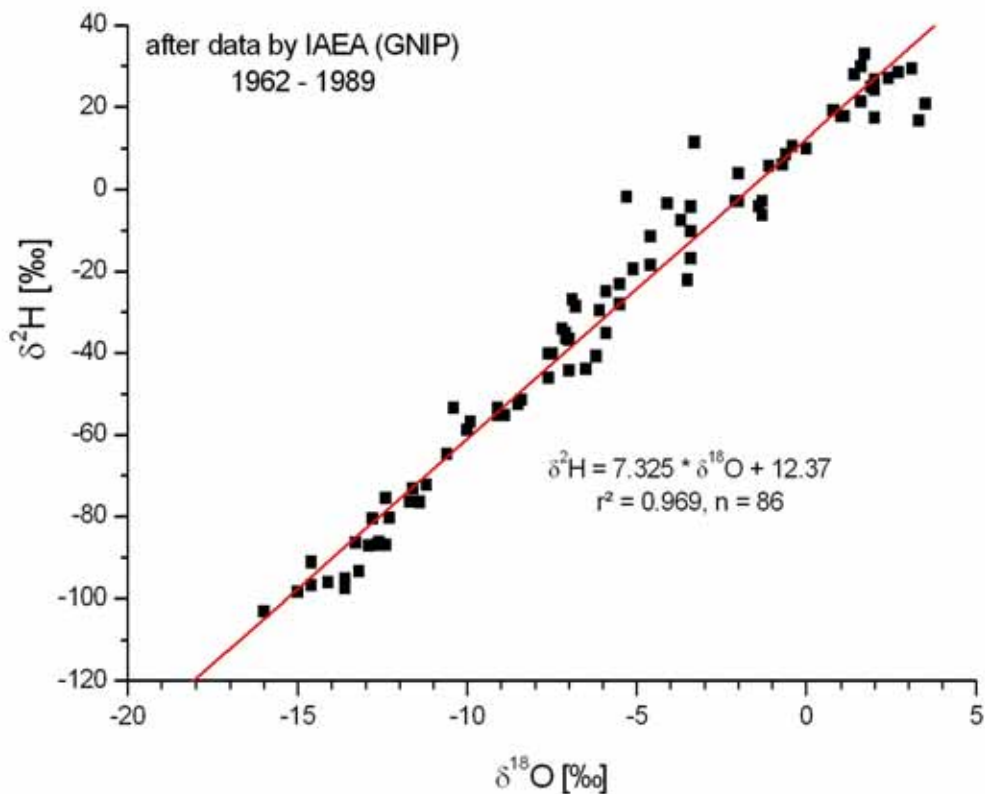
Fig. 4.10: Correlation of Deuterium (^{2}H) and Oxygen-18 in precipitation of Kabul (Karizimir) 1962-1989 and Meteoric Water Line (in red). Data by IAEA (GNIP).
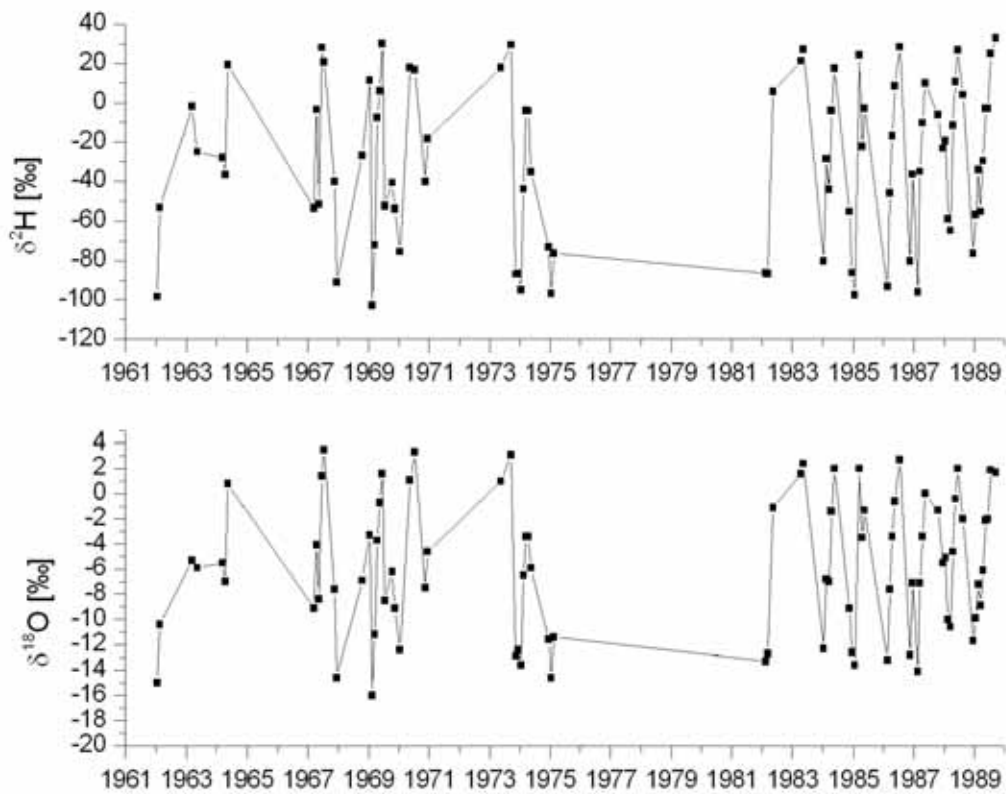
Fig. 4.11: Deuterium (^{2}H) and Oxygen-18 in precipitation of Kabul (Karizimir) 1962-1989. Data by IAEA (GNIP).
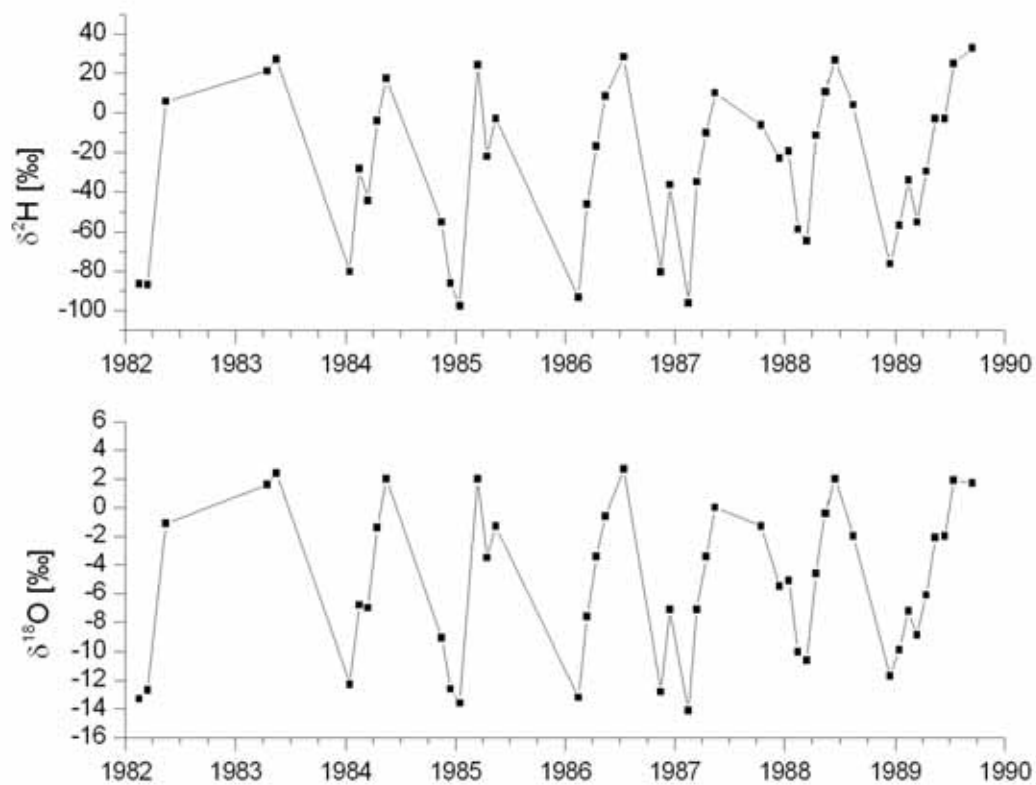
Fig. 4.12: Deuterium (^{2}H) and Oxygen-18 in precipitation of Kabul (Karizimir) 1982-1989. Data by IAEA (GNIP).
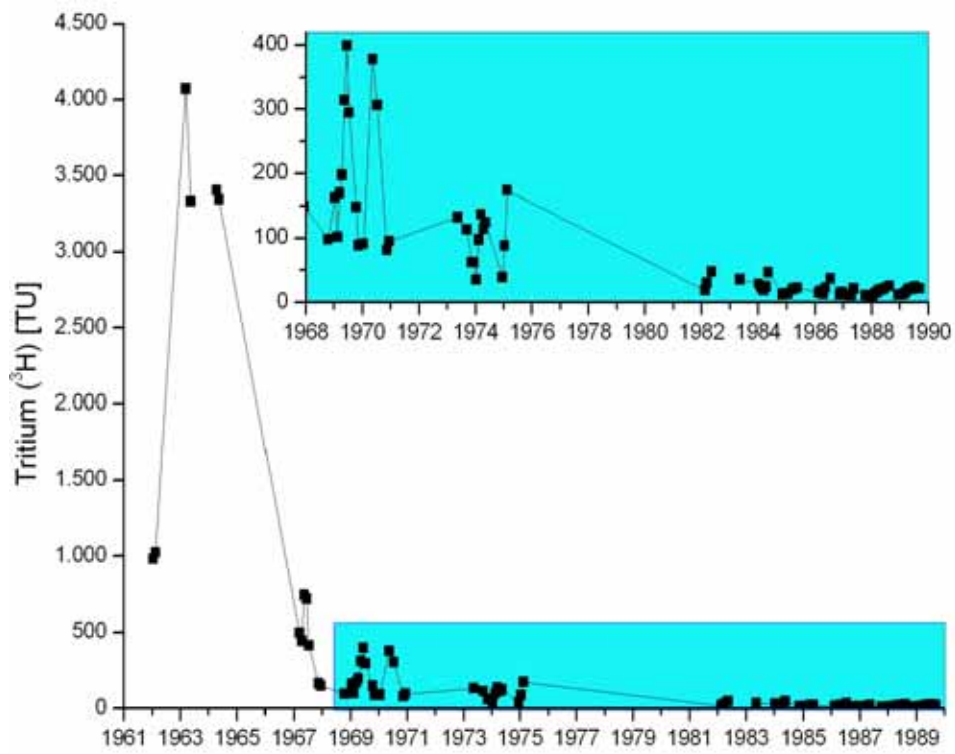
Fig. 4.13: Tritium (^{3}H) in precipitation of Kabul (Karizimir) 1962-1989. Data by IAEA (GNIP).

5. Outlook

The samples from the Kabul Basin reveal an interesting genesis with a number of different processes. It was not possible to completely clarify some of the open questions with the available data.

Balancing some of the hydrochemical components as part of the material flow analysis still requires the chemical analysis of precipitation (rainwater, snow) and surface waters (Logar, Paghman, Kabul) – the latter prior to entry into the Kabul Basin in particular. This would provide much better information on the natural conditions and allow them to be differentiated from the anthropogenic sources.

Depth-specific sampling of groundwater would be helpful to clarify the depth to which the pollutants have penetrated into the aquifer.

An analysis of boron isotopy could be helpful in clarifying the origin of the borate (BARTH 1993, 1998; BASSETT et al. 1995).

The analysis of solid samples from newly drilled wells is required to answer important questions regarding the filtering and buffering properties of the cover sediments (loess) and the aquifer materials. This should primarily involve analysis of the following properties:

- mineralogical and geochemical composition (XRD, XRF, TIC/TOC) of detritus and carbonate cement
- cation exchange capacity and occupation of the exchanger

It is expected that these investigations will also help to reveal the origin of the magnesium. The loess samples could be easily collected from the surface, but boreholes would be required to collect aquifer samples. This can be done during the drilling of water wells.

Useful information on groundwater recharge conditions, mean residence times of groundwater in the aquifers, the influence of evaporation on the water balance and the water quality could be gained from the analysis of water isotopy, i.e. deuterium (^{2}H) and oxygen (^{18}O), possibly supplemented by the analysis of radiogenic isotopes.

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Hannover, June 24, 2005

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Appendix 1: Spatial distribution of groundwater temperatures in the Kabul Basin 2004.

Appendix 2: Spatial distribution of specific electrical conductivities (EC) in the groundwater of the Kabul Basin 2004.

Appendix 3: Spatial distribution of pH in the groundwater of the Kabul Basin 2004.

Appendix 4: Spatial distribution of hydrogen carbonate concentrations in the groundwater of the Kabul Basin 2004.

Appendix 5: Spatial distribution of the redox potentials (Eh) in the groundwater of the Kabul Basin 2004.

Appendix 6: Spatial distribution of the nitrate concentrations in the groundwater of the Kabul Basin 2004.

Appendix 7: Spatial distribution of the nitrite concentrations in the groundwater of the Kabul Basin 2004.

Appendix 8: Spatial distribution of the sulphate concentrations in the groundwater of the Kabul Basin 2004.

Appendix 9: Spatial distribution of the borate concentrations in the groundwater of the Kabul Basin 2004.

Appendix 10: Hydrochemical analysis parameters of the groundwater of the Kabul Basin 2004 (part 1), values above WHO limits shaded.

Nr.	Lokation	X-Koordinate	Y-Koordinate	Datum	Feld-Nr.	LIMS-Nr.	ACY_8,2_mm	Al_mg/l	ALK_4,3_mm	Ba_mg/l	BO2_mg/l	Br_mg/l	Ca_mg/l	Cl_mg/l	Co_mg/l	Cr_mg/l	CU_40_mg/l	EH_mV	F_mg/l	FE_40_mg/l	HCO3_mg/l	K_mg/l	LF_µS/cm	Li_mg/l	Mg_mg/l	Mn_mg/l	Na_mg/l	NH4_mg/l	Ni_mg/l	NO2_mg/l	NO3_mg/l	O2_mg/l	O2 SAT_%	pH	PO4_mg/l	SiO2_mg/l	SO4_mg/l	Sr_mg/l	Temp_°	V_mg/l	Zn_mg/l
1	Shar-e-Naw	3820430	515183	25.04.2004																			1531									0,2	2,7	7,2					16,2		
2	Shar-e-Naw, Kalai Fattulah 12th Street 458	3822451	515263	25.04.2004																			1957									0,1	1,5	7,2					15,8		
3	Shar-e-Naw, Kalai Fattulah 7th Street	3823012	515132	25.04.2004																			1953									1	12,4	7,2					17		
4	Pay Koob-e-Naway 11th Street	3822983	514546	25.04.2004																			2000									2,5		7,3					16,5		
5	Shar-e-Naw Ashraf Wat, Project House 135	3821351	514954	07.05.2004	5	407349	1	0,04	10,8	0,149	4,32	0,19	88,6	85,4	-0,005	0,009	-0,003	203	0,19	0,006	556	6	1310	0,17	73,8	0,002	78	0,01	0	0	40,7	0,3	3,7	7,1	0,02	24,8	71	1,21	15,7	0,007	0,885
6	Baghe-Zanana Sharara	3821346	513859	09.05.2004	6	407350	0,9	0,08	13,8	0,139	8,89	0,27	30,1	189	-0,005	0,006	-0,005	300	0,81	0,007	848	20,4	2080	0,385	147	0,601	167	0,11	0,005	2,61	5,5	0,2	2,8	7,4	0,05	14,6	123	1,03	17,4	0,01	0,618
7	Wazir Muhammad Akbar Khan School	3821257	513372	09.05.2004														333					1834									0,1	1,3	6,9					15,7		
8	Karti Parwan, Naderya High School	3821451	512876	09.05.2004														323					1970									0,2	2,5	6,9					16,7		
9	Barakee-Sharara	3821942	513344	09.05.2004														356					1688									3,8	47,6	7,1					16,7		
10	Old Taymani Road 4th Street	3822689	513772	09.05.2004														377					2030									2,2	27,6	7,2					16,8		
11	Mosque of Mussa e Kalimullah	3822779	513479	09.05.2004														367					1484									0,1	0,1	7,4					16,4		
12	Sher Poor High School	3821969	515313	10.05.2004	12	407351	1,2	0,09	13,5	0,134	5,26	0,2	95,1	142	-0,005	0,005	-0,005	361	0,25	-0,017	719	12,6	1786	0,236	107	0,005	110	0,02	0,017	3,63	85,8	0,2	2	7,2	0,05	33,3	87	1,65	16,1	0,003	0,671
13	Zarghuna High Sshool	3822284	515502	10.05.2004	13	407352	0,9	0,08	10,6	0,099	3,76	0,11	75,5	94,7	-0,005	-0,005	-0,005	400	0,22	-0,02	530	15	1371	0,159	76,5	0,001	78,1	0,96	0,013	0,07	84,6	0,1	1,3	7,4	0,03	33,2	75	1,14	15,4	0,001	0,588
14	10th district 4th street Qalahe Fatullah 8	3822801	515519	10.05.2004														261					1544									0,1	0,9	7,4					15,8		
15	Qala e Fatullah third Street 29	3822541	515780	10.05.2004														325					1225									0,1	1,7	7,4					16		
16	Qalahe Mossa Wakeel Hessain Street	3822770	516150	10.05.2004														352					1368									0,9	11,5	7,4					16,5		
17	Zearat Emamzaman Chargalo wazeer Abad	3823445	516231	10.05.2004		407353	0,6	0,12	8,3	0,083	4,3	0,13	64,6	99,3	-0,005	0,005	-0,005	357	0,24	0,002	531	7,3	1372	0,178	81,3	0,004	93	0,02	0,006	0,05	71,4	1,6	19,7	7,5	0,05	30	88	1,1	15,1	0,002	1,149
18	Karte Mamorin StreeDurkhani school	3821180	511280	11.05.2004	18	407354	0,5	0,01	7,6	0,1	2,29	0,06	66,5	31,3	-0,005	-0,005	-0,005	449	0,42	-0,018	449	8,5	940	0,056	42,6	0,001	64,8	0	0	0	41,9	1,9	23,6	7,4	0,07	28,4	59	1,61	15	0,013	0,044
19	District 5 first Street of Kartemamoreen	3820858	511094	11.05.2004														471					995									0,8	9,4	7,4					15,9		
20	Kabul KPI Masque KPI Street	3821200	510734	11.05.2004	20	407355	0,3	0,01	6,4	0,077	1,35	0,03	54,8	14,6	-0,005	0,006	-0,005	471	0,5	-0,017	385	5,8	747	0,043	36,5	0,001	49,3	0,01	0,041	0,02	18,9	4,7	59,4	7,3	0,09	28,2	56	1,1	16,3	0,012	0,127
21	District 5 Red crosis street	3821789	509293	11.05.2004														476					393									5,8	77,4	7,5					15,5		
22	District No 5 Khushal Khan	3820946	509101	11.05.2004														451					533									7		7,5					15,5		
23	Naheed e Shaheed High School	3820440	508674	11.05.2004	23	407356	0,4	0,02	5,9	0,036	0,51	0,02	73,9	9,6	-0,005	-0,005	-0,005	448	0,23	-0,02	334	2,1	602	0,009	20,5	0,001	24	0	0	0	16	5,5	68,6	7,6	0,03	17	23	0,55	15	0,002	0,17
24	Qute Sangee Qute Sangee Street 425	3818939	510938	12.05.2004														374					547									4,3	54	7,1					15,1		
25	Mahmod Hotaki High School	3818897	511315	12.05.2004	25	407357	0,4	0,03	6,3	0,038	0,71	0,05	91,3	34,7	-0,005	-0,005	-0,005	334	0,26	0,01	377	2,4	787	0,011	28,7	0,001	33	0	0	0	26,2	1,3	16,5	7,4	0,1	19,3	44	0,67	16,1	0,002	0,232
26	Sufee Moh Islam Girls School	3819337	511579	12.05.2004	26	407358		0,03	6,3	0,06	1,01	0,06	85,6	29,8	-0,005	0,006	-0,005	421	0,26	-0,021	370	3	801	0,026	29,6	0,001	38,2	0,02	0,015	0,01	37,6	1,6	20,2	7,4	0,06	21,1	48	0,77	15,3	0,003	0,433
27	Jamal Mena Street Sella	3819770	511259	12.05.2004														371					917									0,5	5,9	7,3					15,7		
28	Karte Sakhee Ministry of Agreecalcture	3819763	512858	12.05.2004				0,04		0,179	4,59	0,2	60	146	-0,005	0,007	-0,005	399	0,105	0,021	551	6,2	156	0,206	107,1	0,006	89	0,07	0,008	0,04	67,8	1,1	13,4	7,3	0,03	26,1	82	1,28	15,6	0,005	1,15
29	Hostal of kabul University University Street	3819622	511730	12.05.2004	29	407359	0,6	0,04	8,7	0,116	1,24	0,1	82,7	49,2	-0,005	-0,005	-0,005	341	0,35	0,015	474	4,2	1053	0,034	46,1	0,022	63,9	0,01	0	0	23	2,7	33,7	7,3	0,05	21,5	72	1,22	15,4	0,008	0,305
30	Wazir Akbar Khan Street 15th 334	3821900	516593	13.05.2004	30	407360	1,5		11									340					1600									0,6		7,1					17,4		
31		3823952	514436																													0,6		7,1							
32	Timany Project Mosque Roundabaout	3823951	514454															353					3280									0,1	1,5	7,4					15,1		
33	Timany Project Street No. 4	3824265	514202	16.05.2004	33	407361	0,9	0,06	12,1	0,023	14,3	0,77	54,2	381	-0,005	0,007	-0,005	345	0,35	-0,017	699	15,2	3240	0,478	179	0,18	376	0,02	-0,005	0	80,1	0,1	1,4	7,4	0,17	28,3	532	1,9	16,1	0,014	0,441
34	Timany Project Street No. 4	3824643	514352	16.05.2004														367					8730									0,4	5,7	7,6					16,5		
35	Khawaja Bughra Mosque	3825188	514295	16.05.2004	35	407362	0,9	0,06	7,1	0,01	86,5	4,99	129	2150	-0,005	0,018	-0,005	304	1,71	0,04	442	115	14590	2,43	522	1,14	2491	0,03	-0,005	0,79	91,8	4,4	57	7,2	0,06	12	4331	7,38	16,8	0,005	0,424
36	3rd Khayerkhana Mosque	3825532	513548	16.05.2004	36	407363	1,4	0,08	7	0,013	13	1,1	342	426	-0,005	0,028	-0,005	330	0,77	-0,01	421	5,7	4860	0,236	256	0,016	441	0,07	-0,005	0,36	65,4	0,1	1,8	7	0,03	19,9	1811	11,6	16,9	0,002	0,54
37	rd Part Ichyarkahana	3826060	513505	16.05.2004														425					2460									2,4	31	7,3					16,6		
38	School No. 12, Khityarkhana Mina	3825825	514010	16.05.2004	38	407364	0,3	0,08	5,4	0,016	5,67	1,1	139	470	-0,005	0,051	-0,005	290	0,9	0,058	318	4,9	3910	0,095	183	0,003	438	0,01	-0,005	0	86,2	1,4	17,8	7,4	0,03	25,1	1050	6,35	16,9	0,008	0,53
39	Wazirabad Mosque Mesbah	3823746	515264	17.05.2004	39	407365	0,3	0,1	7	0,137	3,74	0,13	49,5	78,5	-0,005	-0,005	-0,005	232	0,14	0,013	417	4,9	1008	0,13	66,4	0	54	0,04	-0,005	0	37,8	0,1	1,6	7,5	0,05	26,9	54	0,8	14,3	0,005	0,679
40	Wazirabad 7 Street Kalay Fattulah	3823352	515541	17.05.2004	40	407366	1,4	0,13	11,8	0,158	5,39	0,2	87,4	164	-0,005	0,01	-0,005	306	0,22	0,076	715	8,9	1979	0,254	122	0,003	122	0,03	-0,005	0	126	1,9	23,5	7,2	0,08	32,6	109	1,52	15,8	0,005	0,897
41	Kalay Fathulla 6 Street	3823032	515666	17.05.2004														295					1290									0,3	4,5	7,4					15,6		
42	Kalay Musa Qabr Gora	3822392	516023	17.05.2004	42	407367	1	0,13	8,8	0,111	3,56	0,12	81	84	-0,005	-0,005	-0,005	321	0,12	0,021	517	8,5	1234	0,118	70,3	0,001	63,4	0	-0,005	0	29,4	3,8	46,8	7,2	0,04	24,7	89	1,32	14,9	0,005	0,864
43	Char Kalay Wazirbad Maidani Shir Agha	3823745	516502	17.05.2004														274					1443									0,9	11,3	7,5					15,4		
44	District No.5 Street-Kaema-e-Afshar	3820864	510362	18.05.2004	44	407368	0,1	0,16	6,6	0,113	1,48	0,01	53,5	16	-0,005	0,007	-0,005	363	0,59	-0,011	388	2,6	744	0,035	32,2	0,001	59,2	0	-0,005	0	18,7	3,5	43,7	7,5	0,04	26,4	48	1,04	15,5	0,008	1,22
45	Secondary Girls Schools of Afshar	3820160	510527	18.05.2004	45	407369	0,4	0,21	11,2	0,1	0,92	0,06	86,9	27,7	-0,005	0,005	-0,005	347	0,34	0,058	413	4,3	861	0,024	35,3	0,001	40,9	0,01	-0,005	0	47,7	0,4	4,9	7,4	0,06	24,4	46	0,93	16,4	0,005	1,51
48	District No.5 Dewan Begi	3820231	509307	18.05.2004	46														387					627									4,4	55,2	7,6					15,8		
49	District No.5 Tank-e-tele Dewan Begi	3819866	508917	18.05.2004	49	407370	0,3	0,16	5,3	0,084	0,48	0,01	65,9	8,5	-0,005	-0,005	-0,005	375	0,26	-0,006	306	2	535	0,006	19,2	0	20,2	0,02	-0,005	0	10,4	5,3	65,4	7,7	0,04	17,8	20	0,46	15,2	0,003	1,18
50	Kashal Khan High School	3817556	514570	19.05.2004	50	407371	1,1	0,19	7,7	0,105	3,78	0,17	114	144	-0,005	0,005	-0,005	434	0,29	-0,008	440	5,2	1557	0,179	58,4	0,001	112	0	-0,005	0	122	2,3	29,3	6,8	0,07	23,5	121	0,98	15,5	0,007	1,33
51	Amlriy Secondary School Hyada Shams	3816698	514291	19.05.2004	51	407372	0,1	0,21	7,6	0,075	4,12	0,11	77,1	59,4	-0,005	-0,005	-0,005	316	0,23	0,064	427	4,2	992	0,1	46,6	0,001	50,6	0,01	0,009	0	24	5,1	62,5	7,7	0,03	28,1	51	0,92	14,7	0,004	1,42
52	Bag Raes Cheleston Street	3816152	519216	19.05.2004	52	407373	0,6	0,19	7,4	0,085	4,2	0,1	82,4	64,4	-0,005	-0,005	0,008	359	0,2	0,002	429	4,8	976	0,126	46,4	0,001	49,3	0	0,009	0	25,5	4,8	51,8	7,9	0,04	27,8	50	0,94	15,1	0,001	1,3
53	Agha Aliz Shams Borg	3815625	514206	19.05.2004														355					961									5,7	71,1	7,4					15,5		
54	New Technikum New Technikum Street	3814598	514523	19.05.2004	54	407374		0,28		0,117	3,48	0,14	91,4	65,2	-0,005	-0,005	-0,005	398	0,2	0,03	392	3,9	973	0,112	39,7	0,001	47,6	0	0,008	0	35,5	5,9	73,2	7,4	0,05	23,9	62	0,96	14,9	0,005	1,86
55	New Technikum New Technikum Street	3815311	514805	19.05.2004														411					810									5,4	70,4	7,5					17,5		
57	Khush-hal-Khan Millie Bus Central	3819985	510911	23.05.2004														289					906									0,4	5,6	7,3					15,6		
58	Syllow 4th Street	3819370	510888	23.05.2004														289					969									0,7	8,7	7,3							
59	Darulaman Quala-e-Ali Mardan	3815399	510358	23.05.2004	59	407375		0,02		0,169	3,65	0,12	92,9	40,8	-0,005	0,017	-0,005	301	0,19	-0,02	534	3,7	1087	0,104	53,5	0,006	57	0,01	0,007	0	34,3	4,2	54,5	7,2	0,04	19,6	67	1,27	17,6	0,006	0,04
60	Hydary-mowck Quala-e-Ali Mardan	3814942	510498	23.05.2004	60	407376	0,8	0,04	14,6	0,102	4,2	0,14	82,2	43,8	-0,005	0,007	0,02	305	0,2	-0,011	517	3,4	1062	0,103	55,7	0,026	60,6	0,02	-0,005	0	29,2	5,7	70,8	7,4	0,04	21,2	70	1,55	15,3	0,005	0,489
61	Quala-e-Bakhtyar School	3814396	510514	23.05.2004	61	407377	0,3	0,03	7,4	0,112	3,54	0,12	81,2	46,5	-0,005	0,008	-0,005	296	0,23	0,004	417	2,7	924	0,115	42,8	0,001	46,4	0	-0,005	0	38,5	5,7	70,2	7,3	0,03	19,9	50	1,29	15,3	0,005	0,411
62	Bibi Fatimatazzehra Mosque	3816599	512447	23.05.2004	62	407378	1,5	0,02	12,2	0,179	4,24	0,13	128	113	-0,005	0,006	-0,005	318	0,24	0,022	710	6,7	1652	0,161	77,8	0,004	96,6	0,01	0,015	0,1	62,3	1	12,4	7,1	0,11	23,6	90	1,72	15,1	0,005	0,266
63		3817262	512355	23.05.2004																			2120									3,9	49	7,4					15,5		
64	Haji Yaqub	3821768	515544	24.05.2004	64	407379	0,9	0,02	9,3	0,111	3,69	0,13	84,7	118	-0,005	-0,005	-0,005	315	0,23	-0,021	589	15	1522	0,171	89,5	0,001	87,4	1,69	0,021	0,03	86,7	0,3	4	7,4	0,04	31,5	83	1,31	15,5	0,001	0,122
65	Share-Naw Shaheed Street	3821947	515677	24.05.2004	65	407380		0,02		0,102	3,42	0,22	84,9	88,2	-0,005	-0,005	-0,005	303	0,22	-0,024	538	19,1	1333	0,136	73,7	0	67,5	1,4	0,036	0,02	74	0,3	3,9	7,4	0,03	32,8	76	1,13	15,8	0,001	0,114
66	Share-Naw Shaheed Street	3822190	515827	24.05.2004														362					1099									3	37,3	7,4					15,9		
67	Shier Poor Roas	3821374	516091	24.05.2004														274					1207									1,1	14,4	7,4					15,7		
68	Visastelle Deutsche Botschaft	3820687	516104	24.05.2004	68	407381	0,7	0,02	8,2	0,077	2,98	0,12	85,4	81,5	-0,005	-0,005	-0,005	361	0,185	0,005	473	9,5	1153	0,105	60,8	0	61,8	0	0,023	0	54,4	4,5	57	7,3	0,03	30,7	67	0,93	16,3	0,001	0,297
69	Kalay Hazara Childschool	3818884	515521	24.05.2004	69	407382	0,9	0,04	7,9	0,325	3,57		160	176	-0,005	0,007	-0,005	314	0,185	0,005	449	12	1741	0,131	63,6	0,001	88	0,01	-0,005	0	212	4,6	51,7	7,1	0,03	21,2	97	1,54	15,9	0,002	0,207
70	Quaiti Mosque Alef-Khoshal-Khan-Mena	3818818	515117	24.05.2004	70	407383	0,4	0,05	5,6	0,052	0,6	0,03	68,5	13,3	-0,005	-0,005	-0,005	390	0,261	0,009	325	2,1	612	0,01	22,2	0	29,8	0	-0,005	0	18,4	5,3	67,4	7,4	0,06	19,5	29	0,54	15,6	0,004	0,545
71	Shahid Debory Said Maqsod Shah Mosque	3818449	515637	25.05.2004	71	407384	0,6	0,04	6,4	0,038	0,67	0,09	116	68,7	-0,005	-0,005	-0,005	236	0,119	0,083	365	3,4	926	0,018	29,3	0,001	38,9	0	-0,005	0	23,1	1,9	23,9	7,4	0,08	18,5	69	0,69	15,6	0,002	0,326
72	Wazir Akbar Khan 13 Street 344	3821921	516698	30.05.2004	72	407385	0,9	0,02	9,4	0,149	4,48	0,17	77,8	106	-0,005	0,007	-0,005	321	0,157	0,01	534	5,2	1257	0,154	78,3	0,004	67,3	0,02	-0,005	0,02	46,8	0,2	2,5	7,2	0,03	24,3	60	1,22	15,9	0,006	0,849
73	Wazir Akbar Khan 13 Street 346	3821924	516713	30.05.2004	73	407386	1,1	0,01	10,2	0,182	4,83	0,21	81,1	127	-0,005	0,008	-0,005	336	0,149	0,005	598	5,8	1454	0,19	92,9	0,001	82	0,01	-0,005	0	51	1	12,6	7,2	0,04	25	73	1,31	16,1	0,006	0,246
74	Ghazi Stadium	3819593	517835	30.05.2004	74	407387	1,1	0,02	10,1	0,061	3,81	0,15	96,7	102	-0,005	0,005	-0,005	336	0,096	0,041	579	17,3	1543	0,196	82,9	0,004	112	0,03	0,008	0	16,9	1	13	7,4	0,04	31,3	226	1,08	16,9	0,001	0,152
75	District Shah Sheed 1st Street	3818947	518174	30.05.2004	75	407388	0,6	0,01	8,7	0,119	4,12	0,19	79,2	146	-0,005	-0,005	-0,005	295	0,109	0,006	485	42,4	1515	0,162	76,6	0,001	100	0,05	0,01	0	60,1	0,1	0,5	7,4	0,04	30,8	140	1,02	16,8	0,001	0,059
76	Shah Sheed 2nd Street	3818586	518716	30.05.2004														233					2050									0,1	1,5	7,4					14,8		
77	Shah Sheed 3rd Street	3818496	518888	30.05.2004														252					2130									0,1	0,7	7,5					16,7		
78	Itefaq Mosque	3818385	519140	30.05.2004														258					1981									0,1	1,4	7,7					16		
79	Shah Shaheed- Bibi Shamso	3818160	518643	30.05.2004														293					1665									0,1	1,8	7,4					15,6		
80	School Sarake Kishpomin	3819867	508559	01.06.2004														286					523									5,7	70,3	7,5					14,7		
81	Niazbek, Mosque Haji Yaqub	3819715	508561	01.06.2004														335					523									5,6	68,5	7,6					14,7		
82	Mosque Emani hasan Mujtaba	3818158	510117	01.06.2004			0,3	0,04	4,6	0,1	4,38	0,22	85,6	110	-0,005	0,005	-0,005	255	0,213	0,035	557	6,6	557	0,165	90,1	0,092	89,7	0,04	0,016	0,03	38,7	5	61	7,5	0,07	24,3	159	1,37	14,4	0,001	0,245
83	District 7 Habibia High School	3817874	513604	02.06.2004	83	407389	0,6	0,05	9,6	0,039	0,6	0,03	67,8	16,4	-0,005	-0,005	-0,005	228	0,192	0,045	285	3,1	1480	0,024	19,7	0,001	21,1	0	-0,005	0	11,6	0	0	7,4	0,04	17,1	34	0,43	15	0,003	0,44
84	District 7 Masjet Khagamolah	3817625	513168	02.06.2004	84	407390	0,6	0,03	9,1	0,119	3,67	0,19	87,1	86,6	-0,005	-0,005	-0,005	234	0,19	0,133	521	5,9	1295	0,127	70,8	0,002	80,5	0,01	0,01	0	63,3	1,4	17,8	7,4	0,04	27,3	102	1,25	15,2	0,002	0,214
85	Karti-3 Road -2	3817891	513160	02.06.2004														299					2620									1,5	19,5	7,1							
86	District 3 Abdul Ali Mostaghni High School	3817605	512714	02.06.2004	86	407391	0,8	0,06	9,5	0,15	3,81	0,19	111	126	-0,005	0,005	-0,005	350	0,167	0,008	555	6,3	1648	0,152	75,2	0,029	115	0,01	0,017	0,07	150	1,1	12,1	7,3	0,08	24,6	118	1,42	16,4	0,002	0,447
87	Karti-3 Rukhshana Girls High School	3817494	512710	02.06.2004	87	407392	0,7	0,06	10	0,133	3,71	0,19	101	102	-0,005	-0,005	-0,005	369	0,165	0,012	530	5,7	1445	0,138	68,7	0,012	98,6	0,01	0,012	0	107	1,2	15,2	7,4	0,04	26,8	110	1,28	15,2	0,001	0,425
88	District 3 Road K, Marjet Jamboret	3818058	513143	02.06.2004	88	407393	0,6	0,08	8,1	0,111	2,76	0,15	83	104	-0,005	-0,005	-0,005	236	0,213	0,037	463	5,2	1277	0,114	65	0,012	85,6	0,02	0,008	0	64,2	0,5	6,2	7,4	0,04	26,8	93	1,15	15,8	0,005	0,521
89	Karti-3 Road 3	3817688	513221	02.06.2004	89	407394												287					2240									0,3	4,3	7					14,8		
90	Project Timany	3824012	514562	03.06.2004	90	407395	0,4	0,06	8,5	0,144	6,7	0,41	64,8	297	-0,005	0,008	-0,005	273	0,146	0,032	478	8,1	2190	0,235	153	0,004	144	0,14	-0,005	0	163	0,6	6,7	7,6	0,08	24,6	193	1,61	15,9	0,003	0,433
91	Project Timany 5th Street	3822113	514073	03.06.2004														274					3760									1,8	22,6	7,3							
92	Wazir Akbar Khan Street	3821947	514459	03.06.2004	92	407396	0,7	0,05	11,5	0,03	15,2	0,74	75,9	519	-0,005	0,016	-0,005	380	0,288	0,012	656	11,4	3550	0,43	245	0,002	348	0,01	-0,005	0	277	3,2	41,3	7,4	0,14	30,6	445	9,81	17,4	0,01	0,435
93	Project Timany 5th Street	3824444	514557	03.06.2004														340					4560									1,1	13,1	7,3							
94	Wazir Arbat Kindergarten	3824370	514436	03.06.2004														307					1833									7,6	94,6	7,3					17,4		
95	Project Timany 5th Street	3824849	514920	03.06.2004	95	407397	1,5	0,06	12,5	0,02	23,4	3,7	198	2014	-0,005	0,022	0,005	290	0,183	0,025	740	23,3	10250	0,755	655	0,213	1300	0,17	-0,005	0	149	0,9	8,7	7,3	0,14	22,9	2490	6,26	15,8	0,008	0,362
96	Etlao Saraki-Millie-Bus-Station	3822907	515506	08.06.2004	96	407398	0,6	0,09	8	0,104	1,03	0,06	89,8	28,2	-0,005	0,006	-0,005	383	0,212	0,019	333	32,3	0,004	38,9	0,01	-0,005	50,4	1,2	14,8	7,2	0,05	22,2	45	0,7	15,2			0,598		
97	District No 5, Qurbanke-Awal	3820386	510077	08.06.2004	97	407399	0,4	0,05	6	0,074	0,85	0,05	79,3	25,1	-0,005	-0,005	-0,005	370	0,183	0,015	361	2,3	749	0,025	34,1	0	35,5	0	-0,005	0	12	1,3	16,2	7,3	0,07	20,2	43	0,52	15,6	0,006	0,636
98	District No 5, Spin Kalai Char-Raki-Maktabi	3820386	509744	08.06.2004	98	407400	0,3	0,04	5,2	0,053	0,59	0,04	66,3	12,6	-0,005	0,005	-0,005	343	0,15	0,043	306	1,9	587	0,021	26,6	0,001	26,8	0	-0,005	0	12	5,6	71,1	7,5	0,03	20,2	27	0,49	15,1	0,002	0,646
99	District No 5, Kalai, Askar, Afshari-Silo	3820290	509581	08.06.2004	99	407401	0,2	0,12	5	0,055	0,62	0,03	56,6	9,2	-0,005	-0,005	-0,005	357	0,217	0,019	284	1	509	0,024	22,9	0	21,2	0	-0,005	0	13,7	4,8	60,4	7,5	0,03	18,9	20	0,4	15,5	0,003	0,751
100	Burji-Burji, Kismati-Alef-Khoshal-Mena	3820804	509606	08.06.2004	100			0,19		0,067	3,53	0,11	76,5	50,1	-0,005	-0,005	-0,005	309	0,243	0,023	418	4,3	532	0,108	45,2	0,004	43,7	0	0,012	0	15,9	4,8	60,4	7,3	0,04	21,9	50	1,09	15,7	0,005	1,22
101	Ministry of Irrigation Darluaman Road	3815036	511980	08.06.2004	101	407402		0,11		0,128	3,43	0,09	104,2	13	-0,005	-0,005	-0,005	417	0,13	0,018	564	21,2	902	0,145	88,6	0,001	87,2	0	0,017	2,29	125	7	95,6	7,4	0,03	31,1	86	1,3	15,6	0,003	0,453
103	Zainab Park Cinema	3821318	515816	09.06.2004	103	407403	1,1		10,1									271					1639									1,1	14,4	7,4					15,4		
104	Share-a-Naw Park Street, Park Cinema	3821454	515536	09.06.2004	104	407404	1	0,01	11	0,16	3,9	0,16	84,1	128	-0,005	-0,005	-0,005	304	0,17	0,006	597	13,9	1560	0,185	93,7	0,002	89	0,05	0,025	3,23	89	0,4	5,3	7,4	0,04	31,4	84	1,38	15,4	0,002	0,177
105	Sharara Sharara Hill	3821176	514504	09.06.2004	105	407405	0,5	0,01	8,3	0,116	3,69	0,1	83,3	90	-0,005	0,005	-0,005	299	0,163	0,009	463	5,4	1154	0,12	57,7	0,001	65,7	0	0,029	0	44,3	0,1	0,4	7,3	0,04	25	69	1,03	16,2	0,003	0,506
106	ISAF HQ Well 2	3820945	517759	13.06.2004	106	407406	0,1	0,06	7,4	0,056	2,75	0,11	93,3	71	-0,005	0,005	-0,005	374	0,178	0,008	417	4,3	979	0,11	52,3	0,001	60	0,01	0,009	0	31,3	0,3	5,8	7,6	0,04	27,9	70	0,78	15,7	0,001	0,506
107	ISAF HQ Well 2 new	3821164	517811	13.06.2004	107	407407	0,6	0,05	7,3	0,05	2,81	0,08	74,8	78,6	-0,005	0,006	-0,005	367	0,167	0,017	454	7,9	1052	0,131	50,9	0,009	59,1	0	0,005	0	27	1	1,3	7,4	0,04	26,6	73	0,89	14,9	0,003	0,324
108	Bibimahro	3822147	517964	13.06.2004	108	407408	1,8	0,07	13,8	0,137	5,65	0,26	121,3	179	-0,005	0,012	-0,005	402	0,149	0,043	660	6,1	1936	0,195	110	0,002	124	0,02	0,006	0	50,9	1,4	17,3	7,1	0,06	28,2	109	1,53	16,7	0,005	0,455
109	Qaila-a-khyat Regalaha-Awal	3823266	518517	13.06.2004	109	407409	0,9	0,06	9,9	0,108	4,81	0,15	121	148	-0,005	-0,005	-0,005	379	0,173	0,052	568	8,9	1636	0,162	97,4	0,001	95	0,01	-0,005	0	56,4	0,2	1,9	7,2	0,07	27,1	93	1,39	15,3	0,001	0,378
110	Fort Durrania	3823721	518002	13.06.2004	110	407410	0,8	0,07	8,7	0,073	5,02	0,19	103,9	120	-0,005	0,005	-0,005	369	0,153	0,162	577	6,4	1645	0,182	72,8	0,001	87,5	0,01	-0,005	0	42,6	1,4	16	7,4	0,06	26,7	94	1,27	14,6	0,004	0,678
111	Kalay chaman bibimehro	3824193	518062	14.06.2004	111	407411	0,7	0,13	10,4	0,083	10,4	0,38	82,9	288	-0,005	0,009	-0,005	350	0,159	0,023	620	7,2	2250	0,272	132	0,001	195	0,03	-0,005	0	94,3	0,1	1,7	7,2	0,05	28,7	159	1,93	14,9	0,006	0,678
112	Kalay chaman bibimehro Khatlia Kaka gailon	3824199	518000	14.06.2004	112	407412	0,8	0,11	9,12	0,37	9,4	0,37	84,5	272	-0,005	0,006	-0,005	369	0,153	0,015	635	6	2140	0,262	131	0,001	195	0,06	0,008	0	78,3	0,2	2,3	7,4	0,05	29,5	159	1,39	15,1	0,005	0,703
113	Khuja Bughra Cental Base	3826869	516283	14.06.2004	113	407413	0,2	0,15	3,5	0,029	1,69	0,16	37,9	28,3	-0,005	-0,005	-0,005	422	0,679	0,017	201	2,4	766	0,068	31,8	0,001	81,5	0	-0,005	0	33,6	2,4	57,8	7,8	0,03	26,3	20	1,45	14,9	0,014	1,11
114	Kodga Beghra Mosque	3826925	515076	14.06.2004	114	407414	0,1	0,05	3,9	0,02	0,82	0,11	55,5	33,5	-0,005	0,03	-0,005	304	0,184	0,012	162	2,4	962	0,134	62,3	0	105	0	-0,005	0	30,6	2,3	30,5	7,7	0,03	17,5	65	1,62	15,1	0,004	0,16
115	Short Wave Antenna Radio Afganistan	3821884	519655	07.07.2004	115	407415	0,7	0,04	8,6	0,071	3,11	0,12	55,3	86	-0,005	0,023	-0,005	375	0,007	0,043	508	9,5	1130	0,153	83,6	0,084	54,7	0,01	0,005	0	27,6	0,1	1	7,1	0,04	26,9	57	0,89	14,3	0,002	0,324
116	Poli scharchi Customs Office	3822578	521748	11.07.2004	117	407417	0,6	0,05	11,7	0,11	7,95	0,21	37	187	-0,005	-0,005	-0,005	287	0,334	0,021	691	9,5	1744	0,216	105	0,177	170	0,01	-0,005	0	0,5	12	15,7	7,7	0,3	22,1	107	0,78	17,6	0,01	0,229

- Groundwater geochemistry of the Kabul basin -

Appendix 10: Hydrochemical analysis parameters of the groundwater of the Kabul Basin 2004 (part 2), values above WHO limits shaded.

Nr.	Lokation	X-Koordinate	Y-Koordinate	Datum	Feld-Nr.	LIMS-Nr.	ACY_8,2_mmol	Al_mg/l	ALK_4,3_mmol	Ba_mg/l	BO2_mg/l	Br_mg/l	Ca_mg/l	Cl_mg/l	Co_mg/l	Cr_mg/l	Cu_mg/l	EH_mV	F_mg/l	Fe_mg/l	HCO3_mg/l	K_mg/l	LF_µS/cm	Li_mg/l	Mg_mg/l	Mn_mg/l	Na_mg/l	NH4_mg/l	Ni_mg/l	NO2_mg/l	NO3_mg/l	O2_mg/l	O2_SAT_%	pH	PO4_mg/l	SiO2_mg/l	SO4_mg/l	Sr_mg/l	Temp_°	V_mg/l	Zn_mg/l
118	Police Station 9	3822611	522307	11.07.2004	118	407418	0,5	0,04	10,6	0,109	5,99	0,24	56,8	213	-0,005	-0,005	-0,005	218	0,163	0,114	629	6	1774	0,192	116	0,063	135	0,03	-0,005	0	13	1,7	22	7,6	0,16	27,3	118	1,1	16	0,001	0,215
119	Hood Khel	3822480	523760	11.07.2004	119	407419	0,6	0,06	9,9	0,063	7,17	0,13	37,8	97,8	-0,005	-0,005	-0,005	187	0,01	0,041	597	4	1259	0,165	84,4	0,063	105	0	-0,005	0,39	8,3	0,1	1,7	7,7	0,32	23,4	61	0,73	15,5	0,028	0,317
120	Hood Khel	3822494	524405	11.07.2004	120	407420	0,6	0,03	9,7	0,07	8,02	0,21	35,9	179	-0,005	-0,005	-0,005	154	0,008	0,07	567	5,5	1544	0,152	99,8	0,005	138	0	-0,005	0,04	8,5	0,1	1	7,8	0,05	31,7	101	0,97	16,3	0,001	0,169
121	Poktaist	3822418	526628	11.07.2004	121	407421	1	0,09	11	0,062	4,13	0,13	34	56,9	-0,005	-0,005	-0,005	221	0,28	0,03	421	6,4	998	0,144	69,8	0,106	72,4	0	-0,005	0,06	4	0,2	2,3	7,7	0,32	17,4	112	0,59	16	0,003	0,547
122	Middle School Military Academy	3822969	528124	11.07.2004	122	407422	0,4	0,05	5,1	0,015	14,3	2,57	89,9	1211	-0,005	0,015	-0,005	291	0,404	0,013	297	11,3	5720	0,133	128	0,003	881	0,03	-0,005	0	16,7	1,7	22	7,5	0,04	13,1	743	4,27	18,3	0,007	0,351
123	Salehen Barkat Balta Hesar Shohada	3817983	517361	12.07.2004	123	407423	0,5	0,05	3,5	0,112	3,02		202	277	-0,005	0,006	-0,005	369	0,181	0,008	206	24,6	2200	0,106	79,8	0,001	87,9	0,01	-0,005	0	415	2,1	27,6	7,2	0,05	28,3	180	2,79	18,2	0,011	0,352
124	Bigkcha Sayed Shohada Salehin	3817527	517227	12.07.2004	124	407424	0,2	0,06	3,7	0,131	0,81	0,06	61,1	47,6	-0,005	-0,005	-0,005	328	0,35	0,019	219	8,5	637	0,031	25,3	0	21,4	0	-0,005	0	51,4	3,2	42,9	7,5	0,05	21,5	30	1,09	18	0,014	0,443
125	Qualay Hashmat Khan	3817016	517584	12.07.2004	125	407425	1,7	0,07	8,8	0,059	9,24	0,87	196	699	-0,005	0,011	-0,005	288	0,453	0,023	518	17,2	3500	0,146	133	0,522	330	0,08	-0,005	0	6,1	0,1	1,3	7	0,05	21,7	370	3,97	17,5	0,005	1,21
126	Qualay Hashmat Khan	3816077	518221	12.07.2004	126	407426	0,2	0,12	3,3	0,035	2,55	0,3	75,9	89,5	-0,005	0,007	-0,005	336	0,455	0,016	189	5,7	1035	0,014	38	0,013	83,3	0	-0,005	0	42,1	3,5	46,1	7,6	0,04	27	197	1,23	18,1	0,013	0,896
127	Qualay Hashmat Khan	3816174	518888	12.07.2004	127	407427	0,4	0,08	6,1	0,028	2,8	0,13	76,7	72,1	-0,005	-0,005	-0,005	317	0,235	0,019	359	7,4	950	0,086	41	0,002	57,9	0	-0,005	0	41,1	2,5	31	7,4	0,04	22	66	1,23	14,3	0,009	0,566
128	Bin Hesar	3815989	519917	12.07.2004	128	407428	0,6	0,11	8,8	0,09	5,33	0,23	73,8	106	-0,005	0,009	0,007	301	0,274	0,036	505	44,7	1347	0,181	56,7	0,008	96,5	0,01	-0,005	0,07	38,1	3	38,5	7,4	0,15	22,3	102	1,32	16	0,008	0,665
129	Kart 4, Main Road	3818537	512645	13.07.2004	129	407429	0,4	0,23	6,3	0,038	0,69	0,05	93,9	37,2	-0,005	-0,005	-0,005	246	0,222	0,087	362	2,5	764	0,012	25,9	0,005	32,2	0	-0,005	0	29,7	1	12,3	7,4	0,13	18,1	38	0,61	15,3	0,002	1,49
130	Kart 4, Near Police Station No.3	3818318	512815	13.07.2004	130	407430	0,4	0,26	6,6	0,059	1,08	0,09	79,1	58,2	-0,005	-0,005	-0,005	261	0,349	0,055	377	2,1	888	0,016	39,4	0,046	50,3	0	0,009	0	17,7	0,6	7,2	7,4	0,09	17,2	64	0,75	15,6	0,002	1,74
131	Rabi Belchi Girls High School	3818586	513458	13.07.2004	131	407431	0,4	0,27	6,2	0,045	1,01	0,07	64,3	42,2	-0,005	-0,005	-0,005	302	0,31	0,044	352	2,5	765	0,018	39,5	0,001	39,5	0	-0,005	0	28,4	1,3	16,2	7,5	0,07	20,9	40	0,67	16	0,001	1,7
132	Kart 4, Sarak Awal	3818370	513124	13.07.2004	132	407432	0,9	0,28	9,2	0,13	3,3	0,25	109	184	-0,005	-0,005	-0,005	209	0,3	0,22	506	4,5	1815	0,048	87,9	0,024	137	0,01	-0,005	0,06	86,3	0,3	3,5	7,2	0,08	18,7	191	1,48	15,9	0,002	1,97
133	Kyzargagh Demorad Khan Quala Shah	3817535	514049	13.07.2004	133	407433	0,2	0,26	6,4	0,053	3,18	0,08	63	50,3	-0,005	0,006	-0,005	290	0,15	0,053	356	3,9	792	0,096	41,7	0,015	42,4	0	0,012	0,05	17,6	1,3	15,4	7,6	0,05	24	49	0,58	14,8	0,011	1,63
134	District 7 Mosque	3816389	513596	13.07.2004	134	407434	0,2	0,28	5,6	0,047	2,99	0,08	60,9	54,8	-0,005	-0,005	-0,005	333	0,198	0,044	328	4,7	768	0,081	38,5	0,001	39,9	0	-0,005	0	30,3	3,5	42,2	7,6	0,05	23,6	36	0,43	14,1	0	1,73
135	Timani Project Street 5	3824355	514710	14.07.2004	135	407435	1	0,01	11,4	0,032	15,2	1	91,7	655	-0,005	0,01	0,005	369	0,304	0,011	678	14,5	4140	0,496	269	0,001	370	0	-0,005	0	276	1,2	15	7,3	0,18	29,6	522	2,23	15,7	0,01	0,028
136	Khajabegra Mosque	3825268	515325	14.07.2004	136	407436	0,2	0	4,5	0,013	28,9	3,31	88,9	1360	-0,005	0,01	0,015	262	0,31	0,025	260	26,8	7330	0,597	295	0,142	1129	0	-0,005	0	6,3	2,5	33,6	7,8	0,04	19,6	1847	4,62	18,6	0,004	0,285
137	Khajabegra Midany Project	3825415	515776	14.07.2004	137	407437	0,3	0,02	8,1	0,015	8,1	2	211	834	-0,005	0,01	0,014	215	0,574	0,032	147	13,3	4670	0,336	224	0,301	488	0	-0,005	0	14,2	0,1	1,6	7,6	0,03	31,2	1231	4,47	17,9	0,01	0,45
138	Khajabegra Sharic Danish	3825730	514293	14.07.2004	138	407438	1	0,01	7,3	0,016	8,75	0,99	188	511	-0,005	0,025	-0,005	301	0,566	0,032	433	4,7	4070	0,174	202	0,042	416	0	-0,005	0	97	0,4	5,5	7,1	0,03	22,3	1104	9,54	15,5	0,006	0,032
139	Golaye Khogaboghra	3826220	514254	14.07.2004	139	407439	0,4	0	4,9	0,02	2,69	0,77	102	335	-0,005	0,027	-0,005	310	0,041	0,015	290	3,6	2390	0,052	110	0,001	225	0	-0,005	0	92,7	2,3	29,1	7,3	0,03	25,7	443	3,89	16,1	0,009	0,01
140	Mosque of Kaja Abdullay Ansar	3826308	513475	14.07.2004	140	407440	1,3	0,01	16,8	0,023	4,44		167	369	-0,005	0,006	-0,005	233	0,764	0,837	998	7,1	3180	0,096	174	0,021	270	0,02	-0,005	1,13	111	0,1	1,3	6,7	0,03	37,3	341	9,74	16,3	0,011	0,203
141	Khair Khana, 3rd Part Danesh	3825920	513418	18.07.2004	141	407441	1,5	0,01	11,1	0,032	3,86		114	240	-0,005	0,023	-0,005	257	0,768	0,124	655	4,9	2530	0,086	131	0,002	223	0	-0,005	0,1	117	0,1	1,7	7	0,04	28,4	335	4,81	15,2	0,01	0,009
142	Khair Khana, 2nd Part Cinema	3825943	513120	18.07.2004	142	407442	1,4	0,01	9,4	0,019	5,1		146	233	-0,005	0,019	-0,005	339	0,63	0,021	553	2	2790	0,073	154	0,001	237	0	-0,005	0	149	1,4	17,8	7	0,03	29,2	562	6,6	16,3	0,009	0,024
143	Khair Khana Mariam High School	3826036	512751	18.07.2004	143	407443	0,8	0,01	6,2	0,028	4,08	0,5	125	183	-0,005	0,046	-0,005	307	0,469	0,025	373	2,2	2390	0,052	118	0,001	219	0	-0,005	0	115	1,7	22,1	7,2	0,02	31,7	569	4,81	16,4	0,01	0,017
144	Khair Khana Bazaar Street	3826359	512465	18.07.2004	144	407444	0,3	0	3,7	0,034	2	0,34	77,1	99,6	-0,005	0,01	-0,005	322	0,341	0,018	213	2,8	1387	0,028	59,4	-0,001	115	0	-0,005	0	103	3	38,7	7,4	0,03	38,3	265	2,6	16,8	0,022	0,02
145	Khair Khana, 2nd Part Masjet Street	3826806	512312	18.07.2004	145	407445	0,2	0,02	2,9	0,044	0,77	0,31	64,1	46,5	-0,005	0,004	-0,005	333	0,37	0,041	171	4,2	894	0,016	37,1	0,001	58,9	0	-0,005	0,03	49,3	3,7	48,7	7,6	0,02	38,2	181	1,43	18	0,019	0,022
146	Khair Khana, 2nd Part Aryana	3826893	512798	18.07.2004	146	407446	0,1	0	4,3	0,033	0,81	0,17	40,9	32,3	-0,005	0,006	-0,005	364	0,561	0,023	193	2,3	766	0,015	36,1	0,001	61,5	0	-0,005	0	29,6	3,8	50,6	7,9	0,02	31,6	146	1,76	18,2	0,021	0,104
147	Kulola Poshta Kalai Jangi	3822046	514286	19.07.2004	147	407447	0,3	0,01	6,2	0,076	3,34	0,09	38,8	33,4	-0,005	0,024	0,041	385	0,172	0,021	357	3,9	752	0,06	47	0,002	47,5	0	-0,005	0	10,6	3,6	46,2	7,6	0,02	21,5	51	1,29	16,8	0,007	0,41
148	Timany 6th Street	3822470	514738	19.07.2004	148	407448	1,5	0,01	13,6	0,194	5,78	0,26	92,4	195	-0,005	0,008	-0,005	334	0,206	0,054	758	8,9	2070	0,275	135	0,002	134	0	-0,005	0	100	0,1	0,7	7,4	0,07	34,1	108	1,87	16	0,005	0,436
149	Timany 9th Street	3822687	514465	19.07.2004	149	407449	0,3	0	7,1	0,1	4,04	0,13	47,3	58,3	-0,005	0,013	-0,005	326	0,194	0,012	430	4,7	951	0,124	60,1	-0,001	60,1	0	-0,005	0	14,6	0,2	2,1	7,4	0,05	21,9	53	0,75	15,2	0,008	0,011
150	Timany 12th Street	3823158	513788	19.07.2004	150	407450	0,5	0,01	8,5	0,062	6,3	0,27	50,4	150	-0,005	0,024	-0,005	326	0,219	0,022	495	8,3	1616	0,209	109	0,001	106	0	-0,005	0	70,2	0,3	3,3	7,4	0,1	26,1	134	1,35	15,2	0,01	0,013
151	Timany 13th Street	3822892	514174	19.07.2004	151	407451	1	0,01	11,1	0,074	7,52		68,1	204	-0,005	0,018	-0,005	289	0,235	0,054	669	8,4	2120	0,3	144	0,001	159	0	-0,005	0	141	1,4	17,3	7,3	0,12	33,7	155	1,62	16	0,009	0,077
152	Kart 4 Mosque Saidyl Morsalain	3822366	512085	20.07.2004	152	407452	1	0,01	8,1	0,051	2,63	0,08	77,3	37,6	-0,005	0,007	-0,005	336	0,32	0,084	480	7,2	1085	0,077	54,9	0,001	74,5	0,04	-0,005	0	30,7	2,3	28,2	7,2	0,02	22,3	112	1,7	15,5	0,008	0,195
153	Kart 4 No.11, Middle Street	3822546	511914	20.07.2004	153	407453	1,4	0	10,6	0,1	3,41	0,13	104	117	-0,005	0,005	-0,005	484	0,243	0,019	623	7,2	1585	0,117	72,3	-0,001	122	0	-0,005	0,15	54,7	0,3	3,6	7,1	0,02	23,9	108	2,34	15,5	0,009	0,04
154	Kart 4 Dekepak Girls High School	3822556	511452	20.07.2004	154	407454	0,4	0,01	4,8	0,169	0,9	0,07	76,1	37,2	-0,005	-0,005	-0,005	323	0,255	0,043	288	4,5	759	0,036	30,1	0,001	28,7	0	-0,005	0	61,5	2,4	30,7	7,3	0,03	22,2	39	0,87	16,9	0,012	0,035
155	District 17 Nowabud Dekepak	3822978	511157	20.07.2004	155	407455	0,9	0	4,8	0,157	1,13	0,08	78,2	42,5	-0,005	-0,005	-0,005	404	0,295	0,028	294	5,7	791	0,014	28,4	-0,001	35,8	0	-0,005	0	58,5	1,7	22,1	6,9	0,02	22,5	43	1,44	16,5	0,017	0,27
156	District 17 90 Family	3823230	511557	20.07.2004	156	407456	0,4	0,01	6,8	0,082	3,13	0,08	56	27,4	-0,005	0,009	-0,005	374	0,441	0,028	387	3,9	813	0,051	40,4	-0,001	53,6	0	-0,005	0	31,7	2,4	29,5	7,4	0,03	17,8	48	1,32	15,6	0,01	0,015
157	District 17 Tahee-e-Maskan	3823879	511355	20.07.2004	157	407457	0,1	0,01	4,2	0,052	1,3	0,09	38,7	12,6	-0,005	0,006	-0,005	416	0,416	0,022	252	4,2	569	0,014	27,3	-0,001	38,1	0	-0,005	0	37	3,6	47,2	7,7	0,03	21,2	56	0,84	18,1	0,017	0,066
158	Kart 4 Shaira, AzhmadZai	3821209	514380	20.07.2004	158	407458	1,3	0,01	9,5	0,155	4,62	0,32	117	154	-0,005	-0,005	-0,005	298	0,009	0,044	560	9,7	1545	0,151	72,1	0,003	91	0	-0,005	0,16	44,2	0,2	1,9	7	0,02	24,4	135	1,69	16	0,008	0,148
159	Shar-e-Naw Char Rahi Ansari	3821244	515159	21.07.2004	159	407459	0,8	0	9,5	0,174	4,05	0,12	79,2	64,1	-0,005	0,006	-0,005	278	0,187	0,052	569	7,9	1228	0,162	71,3	0,001	72,3	0	-0,005	0	50,8	1,2	14,8	7,3	0,05	25,5	65	1,16	16	0,007	0,276
160	Shar-e-Naw Saroon Road	3821099	515400	21.07.2004	160	407460	1,5	0,02	13	0,22	4,15	0,29	105	136	0,006	-0,005	0,006	253	0,16	0,037	696	17,9	1705	0,196	94,2	0,036	103	0,67	0,074	7,7	90,7	0,1	1,1	7,1	0,09	30,2	73	1,59	16,1	0,004	0,374
161	Quolla Poshta Street 1	3821802	514413	21.07.2004	161	407461	0,7	0,01	9,9	0,158	4,1	0,14	80,1	86,8	-0,005	0,007	-0,005	345	0,207	0,019	560	6,2	1271	0,148	76,7	0,001	72,2	0,01	-0,005	0	32	4	51,1	7,4	0,03	27,4	73	1,38	16,4	0,005	0,038
162	Quolla Poshta Sharwali-Blak	3822263	513797	21.07.2004	162	407462	0,9	0	11	0,086	6,58	0,18	61,2	122	-0,005	0,009	-0,005	231	0,011	0,034	648	10,1	1525	0,223	96,8	0,002	115	0,01	-0,005	0,22	35	0,2	2,6	7,3	0,12	29,2	93	1,82	15,7	0,009	0,02
163	Quolla Poshta Hoza-e-Nahia-e-Char	3822980	512790	21.07.2004	163	407463	0,3	0,02	10,5	0,046	6,66	0,28	29,2	152	-0,005	0,012	-0,005	310	0,099	0,02	167	9,3	1679	0,135	71,2	0,321	228	0,01	-0,005	2,6	11,5	0,2	2,6	7,6	0,12	15,1	1,81	13,5	0,004	0,078
164	Quolla Poshta Vegetable Market Street	3823508	512328	21.07.2004	164	407464	0,6	0,01	8,4	0,034	17,9	1,39	117	543	-0,005	0,012	-0,005	238	0,62	0,034	467	42,2	5050	0,545	252	9,964	679	0,01	-0,005	0	1,4	0,1	1,1	7,2	0,04	14	1574	5,18	15,3	0,004	0,024
165	Taymascan Mosque Mulla Azam	3823901	511852	21.07.2004	165	407465	0,7	0,01	7,8	0,052	4,38	0,22	60,6	92,6	-0,005	0,014	-0,005	308	0,392	0,021	445	5,4	1237	0,072	67,5	0,005	91	0	-0,005	0	34,6	1,4	17,4	7,4	0,04	17,4	120	2,4	16,3	0,008	0,168
166	Deekeepak Street 1	3824732	511453	21.07.2004	166	407466	0,2	0	4,1	0,029	1,55	0,17	59	43,5	-0,005	0,005	-0,005	338	0,472	0,019	233	5,2	855	0,015	31,4	-0,001	66,9	0	-0,005	0	52,9	2,8	36,5	7,6	0,02	22,8	128	1,38	16,9	0,014	0,026
167	Rahman Mena 200 Family School	3816771	521354	25.07.2004	167	407467	0,4	0,02	8,4	0,103	5,05	0,38	53,3	95	-0,005	0,006	-0,005	314	0,139	0,044	502	10,9	1596	0,196	110	0,023	99,4	0,01	-0,005	0	13,9	2,4	30,5	7,5	0,07	33,3	156	1,99	15,7	0,006	0,177
168	Taymani Khyrul-bashar-Mosque-Street	3824859	513954	25.07.2004	168	407468	1,4	0,02	6,5	0,005	36,2	17	537	7400	-0,005	0,063	0,005	290	0,303	0,004	382	39,1	33100	0,8	2174	0,279	6375	0,01	0,014	0	4,7	0,3	3,5	7,2	0,04	15,8	12356	12,7	15,8	0,005	0,855
169	Khair Khana 3rd Street, Chel-metra	3824715	512916	25.07.2004	169	407469	0,4	0,01	5,4	0,01	4,4	0,91	102	326	-0,005	0,042	-0,005	278	0,418	0,014	319	3,8	3120	0,056	123	0,012	387	0,04	-0,005	0	33,5	0,1	0,5	7,5	0,04	15,8	655	2,85	13	0,007	0,045
170	Imam-Reza-e-Ghareeb Mosque	3824659	511982	25.07.2004	170	407470	0,6	0,01	6,3	0,034	3,29		105	136	-0,005	0,015	-0,005	237	0,454	0,17	365	13,1	1733	0,081	76,5	0,002	129	0,04	-0,005	0	139	1,8		7	0,03	20,9	268	2,8	15,3	0,006	0,049
171	Khair Khana Quala-e-Nagar	3825011	512032	25.07.2004	171	407471	0,6	0,01	7	0,025	4,22		105	163	-0,005	0,039	-0,005	302	0,584	0,023	403	4,7	2120	0,058	89,8	0,001	206	0	-0,005	0	131	1,3	17	7,2	0,03	21,4	413	4,03	16,8	0,008	0,047
172	Khair Khana Market Street	3825458	512072	25.07.2004	172	407472	1,2	0,02	7,8	0,027	4,1		143	165	-0,005	0,04	-0,005	272	0,374	0,126	473	7,3	2300	0,053	108	0,003	177	0,03	-0,005	0	232	1,5	18,7	7,1	0,02	28,9	394	3,58	16,9	0,009	0,287
173	Khair Khana 2nd Street	3825928	512316	25.07.2004	173	407473	0,7	0,01	6,8	0,024	3,74		109	150	-0,005	0,054	-0,005	386	0,739	0,021	408	1,9	2100	0,055	112	0,001	168	0,04	-0,005	0	123	3,9	49,4	7,3	0,02	22,3	456	4,88	16,5	0,009	0,033
174	Khair Khana Post Office	3826321	511660	25.07.2004	174	407474	0,3	0,01	3,7	0,031	1,53	0,25	68,4	65	-0,005	0,007	-0,005	361	0,417	0,023	211	5,8	1018	0,018	49,6	0,001	71,5	0	-0,005	0	73,6	2,8	35,5	7,4	0,02	29,9	362	2,27	17,6	0,018	0,028
175	Khair Khana Quala-e-Hesae-Awal	3825529	511522	25.07.2004	175	407475	0,6	0,01	6,1	0,022	1,89	0,49	104	111	-0,005	0,008	-0,005	359	0,401	0,025	249	5,6	1542	0,026	50,5	0,001	112	0	-0,005	0		2,8	35,5	7,6	0,02	29,9	362	2,27	17,3	0,011	0,378
176	Sarak-e-chalstoon	3818750	514958	27.07.2004	176	407476	0,5	0,02	6,4	0,072	3,04	0,1	80,6	50	-0,005	0,007	-0,005	448	0,139	0,034	374	4,7	876	0,089	36,3	0,001	42,6	0	-0,005	0	27	3,6	44,2	7,3	0,03	20,2	58	0,71	14,1	0,002	0,378
177	Jad-e-Maiwand Sarajee	3819188	517139	27.07.2004	177	407477	0,3	0,01	9,7	0,137	4,55	0,22	89,9	91	-0,005	0,012	-0,005	373	0,129	0,017	585	82	1987	0,17	80,7	0,001	129	0,01	0,019	0	87,2	4	50,7	7,6	0,07	30	142	1	15,7	0,007	
178	District No. 8 Ghalaya-e-Jadeed	3818062	518446	27.07.2004	178	407478	0,4	0,01	9,2	0,143	4,9	0,31	70,8	112	-0,005	0,005	-0,005	174	0,196	0,056	548	9,8	1403	0,208	79,4	0,53	95,4	0,02	0,007	0,06	0	1	14,9	7,7	0,33	19,6	126	1,24	13,3	0,001	0,045
179	District No. 8 Ghalaya-e-Jadeed	3817417	518077	27.07.2004	179	407479	0,4	0,01	9,6	0,131	6,23	0,38	71,8	124	-0,005	0,009	-0,005	383	0,261	0,012	569	8,3	1560	0,213	94,2	0,014	144	0,01	0,015	0	2,4	0,2	2,6	7,7	0,15	25,5	134	1,04	13,3	0,006	0,049
180	District No. 8 Charaye-Ansari	3816719	519513	27.07.2004	180	407480	0,2	0,02	10,1	0,106	4,84	0,16	50,1	111	-0,005	0,007	-0,005	209	0,238	0,038	424	8,1	1275	0,17	64,3	0,1	103	0	0,009	0	3,3	1,6	20	7,9	0,2	25,5	90	0,93	14,5	0,004	0,042
181	District No. 8 Ben-i-hesar	3815700	520079	27.07.2004	181	407481	0,6	0,01	9,9	0,107	6,42	0,21	55,9	101	-0,005	0,007	-0,005	382	0,377	0,032	555	17	1481	0,275	91,7	0,001	109	0,1	-0,005	0	37,3	3,1	39,8	7,4	0,1	21,5	157	1,27	16,8	0,005	0,14
182	District No. 8 Pull-e-Safeed Ben-e-hesar	3815666	519686	27.07.2004	182	407482	0,6	0,01	8,1	0,085	4,69	0,21	53,2	94	-0,005	0,005	-0,005	387	0,231	0,066	466	5,3	1246	0,207	73,9	0,001	84,2	0,02	-0,005	0	8,3	1,9	24,4	7,7	0,16	25,1	114	1	13,7	0,006	0,135
183	Rahman Mena 1st Street	3818624	520082	28.07.2004	183	407483	0,6	0,01	7,6	0,039	5,41	0,2	60,1	96	-0,005	0,006	-0,005	352	0,292	0,023	441	12,4	1201	0,221	73,2	0,001	73	0,01	-0,005	0	36,7	3	37,5	7,4	0,08	15,9	176	0,99	15,1	0,006	0,043
184	Sha Sang New street of Kart-e-Naw	3818854	519672	28.07.2004	184	407484	0,6	0,02	10,5	0,025	8,13		116	90	-0,005	0,007	-0,005	376	0,159	0,034	349	25,9	2150	0,226	115	0,002	220	0	-0,005	0	200	1,3	16,6	7,7	0,03	16,1	302	2,5	15,3	0,006	0,024
185	Shah Shaheed 2nd Street	3818883	518813	28.07.2004	185	407485	0,8	0,01	11,6	0,113	6,35	0,26	110	148	-0,005	0,007	-0,005	363	0,251	0,011	651	11,5	1765	0,191	116	0,001	118	0	-0,005	0	42,3	3,6	45,2	7,7	0,05	16,5	180	1,5	17,1	0,003	0,173
186	Tymany Street 10	3822562	514021	29.07.2004	186	407486	0,9	0,01	10,4	0,055	6,45		87,1	174	-0,005	0,013	-0,005	275	0,218	0,02	663	7,6	1884	0,247	118	0,002	157	0	-0,005	0	126	1,3	23,9	7,2	0,12	30,7	118	1,96	15	0,007	0,173
187	Tymany Street 10	3822679	514302	29.07.2004	187	407487	1,7	0,01	13,9	0,071	7,74		92,4	232	-0,005	0,013	-0,005	283	0,212	0,03	774	11,1	2500	0,345	162	0,003	163	0	-0,005	0	239	0,4	5	7	0,04	34,1	143	2,12	16,2	0,008	0,04
188	Tymany Street 10	3823057	514653	29.07.2004	188	407488	0,9	0,01	9,4	0,089	4,68	0,32	52,5	111	-0,005	0,008	-0,005	286	0,139	0,028	539	6,8	1303	0,179	94,6	0,001	73,8	0,01	0,009	0	35	0,4	5,5	7,4	0,04	27,9	72	1,06	15,4	0,004	0,04
189	Old District of Tymany Street 14	3823208	514313	29.07.2004	189	407489	1,5	0,01	9,9	0,098	5,52	0,2	55,3	173	-0,005	0,005	-0,005	246	0,169	0,044	473	6,9	1643	0,192	112	0,002	121	0,01	0,3	3,9	7,4	0,09	27,9	105	1,11	15,9	0,008	0,068
190	Sarak Wazirabad	3823395	514012	29.07.2004	190	407490	1,1	0,02	9,7	0,099	7,7	0,48	69,2	195	-0,005	0,007	-0,005	256	0,169	0,045	573	9,9	1892	0,202	123	0,004	104	0,01	0,01	0	72	0,4	4,4	7,3	0,04	22	101	1,21	15,6	0,005	0,054
191	Sarak Wazirabad	3823610	514396	29.07.2004	191	407491	1	0,01	9,3	0,085	5,75	0,54	52,1	121	-0,005	0,007	-0,005	270	0,16	0,03	491	7,5	1359	0,184	93,6	0,002	87,1	0,01	0,01	0	63	0,5	6,5	7,4	0,04	21,9	78	1,17	15,4	0,005	0,04
192	Tymany	3823690	514126	29.07.2004	192	407492	1	0,01	12,5	0,055	15,4	0,55	64,1	395	-0,005	0,013	-0,005	321	0,14	0,033	762	15,8	3300	0,483	221	0,001	281	0,01	0,019	0	267	1,4	17,3	7,3	0,04	31	313	1,95	16	0,01	0,041
193	Tahia-e-Maskan	3823672	511578	01.08.2004	193	407493	0,6	0,01	7,3	0,083	2,27	0,12	58,1	48,8	-0,005	0,008	-0,005	394	0,26	0,021	420	3	926	0,053	46,9	-0,001	70,7	0	-0,005	0	32,9	1,9	24,6	7,3	0,03	18,9	59	1,12	14,4	0,008	0,009
194	Kolola Pushta 2nd part od Parwan	3822498	512859	01.08.2004	194	407494	1	0	10,6	0,076	3,86	0,09	84,6	100	-0,005	0,005	-0,005	252	0,01	0,032	652	11,8	1551	0,169	86	0,118	115,4	0	-0,005	0	116	0,3	3,7	7,1	0,05	27,8	103	2,85	15,7	0,002	0,204
195	Kolola Pushta Shara-Ara	3822603	513837	01.08.2004	195	407495	0,6	0	8,6	0,057	4,99	0,13	49,7	126	-0,005	0,005	-0,005	363	0,19	0,016	493	5,4	1353	0,126	88,1	0,001	125	0	-0,005	0	46,8	0,1	1,5	7,1	0,06	15,4	112	1,97	15,3	0,004	0,199
196	Tymany Pay Kobe Naswar	3823664	514813	01.08.2004	196	407496	0,5	0	7,1	0,133	3,96	0,16	54	105	-0,005	0,006	-0,005	341	0,12	0,019	414	4,7	1193	0,124	66,6	0,001	92,5	0,01	-0,005	0	25,2	0,2	2,7	7,1	0,06	21,5	97	1,78	15,5	0,006	0,078
197	Tymany 2nd part	3823360	514815	01.08.2004	197	407497	0,9	0	9,4	0,091	4,31	0,18	42,9	118	-0,005	0,005	-0,005	366	0,12	0,018	514	4,1	1082	0,114	63,7	0,001	102	0	-0,005	0	31	0,1	1,8	7,2	0,06	19,1	75	1,63	16	0,005	0,088
198	Quala-e-Fatullah 5th Street	3822927	514576	01.08.2004	198	407498	0,3	0	5,8	0,121	3,37	0,11	57,3	69,9	-0,005	0,008	-0,005	397	0,12	0,019	294	4,1	934	0,061	53,4	0,001	52,9	0	-0,005	0	39,1	0,7	9,4	7,3	0,04	24,2	58	0,74	15,9	0,007	0,034
199	Khair Khana Ariana	3826596	512688	01.08.2004	199	407499	0,3	0,01	4,2	0,041	0,91	0,25	55,9	36,5	-0,005	0,007	-0,005	382	0,38	0,042	192	2,3	764	0,019	37,5	-0,001	43,6	0	-0,005	0	36,6	3	38,2	7,5	0,02	33,3	120	1,28	16,6	0,012	0,014
200	Khair Khana Ariana	3826184	512618	01.08.2004	200	407500	0,3	0	3,8	0,042	0,9		59,6	40,2	-0,005	0,006	-0,005	382	0,47	0,036	207	2,6	835	0,02	33,7	0,001	49,1	0	-0,005	0	54,1	2,9	38,4	7,7	0,02	34,2	124	1,31	16,8	0,01	0,018
201	Khair Khana Ariana	3826561	513134	01.08.2004	201	407501	0,2	0	3,2	0,04	0,83	0,28	42,9	29,5	-0,005	0,007	-0,005	384	0,36	0,038	173	2	637	0,015	26,1	0,001	46,2	0	-0,005	0	26,1	3,1	40	7,7	0,02	34	99	1,15	16,5	0,009	0,016
202	Khair Khana Cinema	3825656	512853	01.08.2004	202	407502	0,6	0,01	6,3	0,041	3,43		100	164	-0,005	0,006	-0,005	296	0,33	0,088	444	3	2060	0,028	77,3	0,001	210	0,01	-0,005	0	133	3,5	18,8	7,3	0,03	20,5	396	4,56	16,8	0,011	0,067
203	MMI	3819933	516670	02.08.2004	203	407503	0	0,01	8,2	0,074	2,87	0,14	84,2	82,9	-0,005	-0,005	-0,005	356	0,13	0,021	478	4,9	1148	0,098	66,1	0,001	66,1	0	0,021	5,51	43,4	0,9	11,5	7,3	0,04	25,1	64	0,93	15,2	0,001	0,067
204	MRRD	3820374	516954	02.08.2004	204	407504	0	0,02	9,1	0,102	3,13	0,15	108	93,7	-0,005	-0,005	-0,005	344	0,13	0,029	556	11	1383	0,104	66,8	0,001	75,3	0,01	0,032	1,67	91	0,7	2,4	7,2	0,03	29,8	85	1,09	15,4	0,005	0,014
205	Wazirabad Mosque M. Hanifa	3824083	515585	04.08.2004	205	407505	0	0,03	8,3	0,076	8,56		76,5	387	-0,005	0,009	-0,005	347	0,14	0,028	577	10,5	2700	0,321	195	0,01	191,6	0	-0,005	2,35	235	1,1	137,6	7,5	0,11	30,3	223	1,53	17,3	0,01	0,099
206	Macrorayan Post	3820884	516883	04.08.2004	206	407506	0	0	9,5	0,054	86,3		86,8	170	-0,005	0,007	-0,005	338	0,09	0,025	519	9,1	1066	0,118	83,3	0,001	109	0,1	-0,005	0	5,6	4,1	52,1	7,4	0,06	32,7	76	1,18	15,5	0,005	0,047
207	Darwaza-e-Lahori German Hospital	3819001	517740	08.08.2004	207	407507	0	0,07	9,7	0,064	4,16	0,16	62,6	83,1	-0,005	0,009	-0,005	286	0,07	0,05	428	54	1056	0,151	58,7	0,002	90,5	0,01	10,8	9,45	13,8	0,4	5,2	7,6	0,05	20,7	94	0,84	16,4	0,004	0,03
208	Amani School	3820381	516832	08.08.2004	208	407508	0	0,02	7,6	0,053	3,03	0,11	81,7	74,1	-0,005	0,008	-0,005	324	0,11	0,024	454	9	1046	0,113	58,5	0,001	55,9	0,01	0,007	0	30,9	4,2	53,4	7,5	0,04	24,7	62	0,84	15,5	0,003	0,049
209	Aishe-e-Durani School Pule-Baghe-Amani	3819546	516112	08.08.2004	209	407509	0	0,02	7,4	0,063	3,08	0,1	81,7	74,1	-0,005	0,007	-0,005	354	0,3	0,026	436	4	1046	0,129	65,8	0,001	55,6	0,01	0,007	0	31,8	3,9	50,5	7,6	0,07	23,8	69	0,99	15,4	0,004	0,07
210	Dumama-e-Latoun Ali Shohada	3817888	515597	08.08.2004	210	407510	0	0	6,9	0,084	3,5	0,15	62,2	82,5	-0,005	0,006	-0,005	330	0,22	0,02	416	5,6	1005	0,124	50,5	0,001	73,3	0,01	0,008	0	18,3	3,5	44,7	7,5	0,03	24,7	88	0,98	15,7	0,004	0,062
211	Darulaman School Pule-Baghe-Amani	3817896	515587	08.08.2004	211	407511	0	0,01	8,1	0,09	3,18	0,15	70,8	82	-0,005	0,006	-0,005	327	0,14	0,02	434	5,3	1034	0,137	57,3	0,001	73,9	0,01	0,007	0	16,3	4,1	51,9	7,5	0,03	24,7	77	0,96	15,6	0,004	0,051
212	Khane Polat Maidana 500 Families Project	3822682	511336	08.08.2004	212	407512	0	0,01	7,4	0,03	3,07	0,11	86,5	75	-0,005	0,006	-0,005	321	0,28	0,026	428	5,2	989	0,024	26,9	0,001	49,1	0	0,006	0	40,2	3	38,6	7,4	0,04	18,2	74	1,23	15,2	0,004	0,076
213	Karti Parwan Mosque of Eman Azam	3821453	512734	09.08.2004	213	407513	2	0,01	10,9	0,338	1,43	0,01	182	162	-0,005	0,007	-0,005	338	0,07	0,118	567	18,1	2110	0,027	82,8	0,492	124	0,01	21,6	236	0,5	6,5	7,4	0,04	26,4	146	4,07	15,1	0,006	0,013
214	Karti Sanat Teaching Training Said Jamaludin	3820652	513380	09.08.2004	214	407514	0,6	0,01	6,1	0,035	1,08		68,4	21,4	-0,005	0,005	-0,005	303	0,14	0,015	370	3,7	658	0,009	24,8	0,001	22,8	0	-0,005	0	11,2	0,3	4	7,5	0,04	26,4	36	0,56	14,1	0,002	0,168
215	Intersection Puli Surkh	3819084	513297	09.08.2004	215	407515	0,6	0	7,6	0,028	1,35	0,06	68,1	21,5	-0,005	0,006	-0,005	381	0,11	0,016	412	3,3	706	0,011	27,1	0,001	31,3	0	-0,005	0	11,3	0,9	11,8	7,6	0,03	15,4	44	0,73	14,8	0,003	0,02
216	Darulaman Allaudin Station Pump	3819173	512975	09.08.2004	216	407516	0,6	0	9,8	0,048	2,65	0,02	77,3	81,4	-0,005	0,007	-0,005	387	0,09	0,024	475	5	937	0,013	45,4	0,001	52,9	0,01	-0,005	0	36,3	3,2	41,1	7,6	0,04	23,8	54	0,81	15,1	0,004	0,308
217	Darulaman School Pumpshaft	3819221	513312	09.08.2004	217	407517	0,6	0	6,9	0,041	1,08		68,8	21,5	-0,005	0,005	-0,005	345	0,11	0,011	424	3,5	664	0,008	27,3	0,001	27,6	0	-0,005	0	9,2	2,7	34,8	7,6	0,03	15,4	39	0,6	14,6	0,002	0,021
218	Darulaman Elmfarhang Dekmazang	3819343	513973	09.08.2004	218	407518	0,6	0	10,3	0,033	3,33	0,18	81,5	101	-0,005	0,007	-0,005	477	0,11	0,026	496	7,8	1060	0,02	52,1	0,001	70,8	0,01	-0,005	0	80,1	3,3	40,5	7,4	0,03	16,5	64	1,09	15,2	0,005	0,07
219	Darulaman Fabrika Hajari Adit	3819764	514260	09.08.2004	219	407519	1,5	0,01	10,1	0,076	4,34	0,28	98	99,1	-0,005	0,006	-0,005	368	0,11	0,025	592	7,9	1590	0,032	56,5	0,001	81,4	0,01	-0,005	0	42,9	4	50	7,6	0,04	25,8	98	1,8	15,1	0,007	0,118
220	Khashad Hkan Techer Training Academy	3820966	510374	10.08.2004	220	407520	0,6	0,01	10,6	0,06	7,77	0,13	40,6	142	-0,005	0,008	-0,005	361	0,14	0,02	448	10,7	1524	0,145	77,5	0,001	169	0	-0,005	0	6,9	2,3	29,1	7,4	0,04	19,4	157	1,11	14,6	0,005	0,042
221	Karte-e-Naw Embassy of Iran	3824628	514029	16.08.2004	221	407521	0,6	0,02	9,9	0,06	4,74	0,2	44,5	116	-0,005	0,008	-0,005	349	0,15	0,022	441	5,8	1280	0,168	56,4	0,001	96	0,02	-0,005	0,42	58,9	0,5	6,4	7,5	0,04	20,6	67	1,23	16,5	0,005	0,144
222	Darulaman-e-Girls High School	3819230	514613	16.08.2004	222	407522	1	0	11,3	0,089	3,96	0,14	90,4	111	-0,005	0,008	-0,005	344	0,11	0,02	650	8,8	1359	0,036	65,2	0,001	79,5	0	-0,005	0	21,6	5,7	72,2	7,8	0,03	21,5	71	1,65	15,2	0,008	0,042
223	Shash Darak Radio Afghanistan	3820894	517169	16.08.2004	223	407523	1,1	0,01	11,8	0,094	5,66	0,22	97,3	149	-0,005	0,009	-0,005	332	0,11	0,013	718	10,4	1686	0,216	82,2	0,001	85,2	0	-0,005	0	5,7	4,3	55	7,6	0,04	24,6	97	1,24	16,5	0,006	0,042
224	Wazir Akbar Khan BKA-House	3821902	516633	16.08.2004	224	407524	2,3	0,01	14	0,077	8,16	0,27	72,2	165	-0,005	0,009	-0,005	330	0,11	0,011	793	10,3	2110	0,241	121	0,001	107,8	0,01	-0,005	0	57,6	3,3	42,5	7,4	0,04	28,6	111	1,46	16,5	0,007	0,053
225	German Embassy	3821115	516431	16.08.2004	225	407525	1,1	0	9,9	0,077	3,09	0,11	81,6	69,1	-0,005	0,006	-0,005	363	0,1	0,017	474	6,5	1088	0,127	57,3	0,001	55,2	0	-0,005	0	29,2	3	38	7,4	0,04	23,8	61	0,98	16,4	0,002	0,152
226	Wazir Akbar Khan Mosque	3821543	516748	16.08.2004	226	407526	0,5	0,01	7,5	0,053	2,55	0,1	72,9	45,1	-0,005	0,007	-0,005	330	0,18	0,037	357	4,3	885	0,017	33,3	0,001	36,1	0	-0,005	0	13,7	3,3	42,3	7,7	0,03	26,9	54	0,86	16,9	0,005	0,036
227	District 9 Fazil Big Afshar Well #8	3819744	506195	16.08.2004	227	407527	0,4	0,01	6,2	0,061	3,4		63,4	68,9	-0,005	0,005	-0,005	345	0,11	0,016	378	7	872	0,01	33,8	0,001	57,6	0	-0,005	0	41,4	3,1	38,9	7,4	0,05	17,5	44	0,76	14,7	0,004	0,026
228	District 5 Fazil Big Ahmad Well #6	3819543	506123	16.08.2004	228	407528	0,4	0	4,9	0,03	0,69	0,04	70,7	7,5	-0,005	-0,005	-0,005	399	0,1	0,011	281	2,4	559	0,007	18,3	0,001	16,5	0	-0,005	0	13,3	0,5	6,5	7,6	0,03	15,9	34	0,51	14,6	0,003	0,033
229	District 13 Sharak Safa Afshar Well #5	3818351	506127	16.08.2004	229	407529	0,4	0,01	5,4	0,03	0,64	0,04	70,7	7,5	-0,005	0,01	-0,005	399	0,11	0,012	281	2	559	0,005	18,3	0,001	16,5	0,01	-0,005	0	21,7	0,6	7,7	7,6	0,03	14,4	49	0,76	14,7	0,003	0,061
230	Mogabete Sanat Heratee KPI Deep Well #2	3816295	525961	16.08.2004	230	407530	0,6	0,01	6,8	0,042	3,7		77,7	76,5	-0,005	0,006	-0,005	436	0,23	0,017	470	6,7	987	0,014	38	0,001	58,9	0,01	-0,005	0	35	2,9	36,6	7,4	0,04	16,9	78	1,08	15,5	0,004	0,041
231	Bagrame Village Logar Wellfield Well #10	3815477	525910	16.08.2004	231	407531	0,6	0,01	9,2	0,038	2,7		79,6	100	-0,005	0,005	-0,005	436	0,11	0,027	493	8,4	1190	0,016	47,4	0,001	94,2	0,01	-0,005	0	12,5	2,9	36,6	7,5	0,04	17,5	94	1,25	14,6	0,005	0,044
232	Fazil Beg	3820704	506557	04.05.2004		407534		0,03		0,019	0,02		52,8	8,8	-0,005	-0,005	-0,005	150	0,16	0,01	219	3,2	414	0,01	12,4	0,076	12,9	0	-0,01	0,16	12,9	1,1	13,5	7,7	-0,02	13	19	0,31	14,6	-0,005	0,122

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Appendix 11: Calculated hydrochemical parameters of the groundwater of the Kabul Basin 2004 (part 1).

Nr.	Location	x_long	y_lat	calcite	aragonite	dolomite	gypsum	anhydrite	barite	strontianite	celestite	SAR	Total Hardness	Carbonate Hardness	Ca/Mg
5	Shar-e-Naw Ashraf Wat, Project House 135	3821351	514954	0,09	-0,06	0,33	-1,81	-2,06	0,41	-1,27	-1,98	2,09	29,53	30,24	0,73
6	Baghe-Zanana Sharara	3821346	513859	0,04	-0,11	1,01	-2,15	-2,39	0,47	-0,94	-1,91	3,94	38,34		0,12
14	Sher Poor High School	3821969	515313	0,26	0,11	0,80	-1,76	-2,01	0,37	-1,00	-1,83	2,60	38,14	37,80	0,54
15	Zarghuna High Sshool	3822284	515502	0,26	0,11	0,74	-1,85	-2,10	0,26	-1,06	-1,97	2,14	28,32	29,68	0,60
19	Zeiarat e Emamzaman Chargalq e wazeer Abad	3823445	516231	0,31	0,16	0,93	-1,85	-2,10	0,26	-0,95	-1,92	2,57	27,91	23,24	0,48
20	District 5 Karte Mamorin StreeDurkhani school	3821180	511280	0,20	0,05	0,41	-1,93	-2,18	0,25	-0,91	-1,85	2,16	19,19	21,28	0,95
22	Kabul KPI egala KPI Street	3821200	510734	0,04	-0,11	0,13	-2,00	-2,25	0,13	-1,16	-2,00	1,79	16,14	17,92	0,91
25	District No 5 Naheed e Shaheed High School Qalahe Wazeer Part B Khushal Khan	3820440	508674	0,32	0,17	0,30	-2,21	-2,46	-0,50	-1,30	-2,64	0,90	15,10	16,52	2,19
27	Mahmod Hotaki High School Qalahe Sangee	3818897	511315	0,30	0,15	0,33	-1,90	-2,15	-0,29	-1,33	-2,33	1,09	19,44	17,64	1,93
28	Sufee Moh Islam Girls School Street of Kabul University	3819337	511579	0,24	0,08	0,22	-1,88	-2,13	-0,04	-1,31	-2,23	1,28	18,85	17,64	1,75
30	Karte Sakhee Ministry of Agriculture	3819763	512858	0,11	-0,04	0,70	-1,95	-2,20	0,52	-1,06	-1,92	2,25	33,26	0,00	0,34
31	Hostel of Kabul University University Street	3819622	511730	0,19	0,04	0,34	-1,77	-2,02	0,37	-1,14	-1,90	1,97	22,27	24,36	1,09
35	Timany Project Street No. 4	3824265	514202	0,14	-0,01	1,03	-1,38	-1,63	0,16	-0,81	-1,13	7,83	49,14	33,88	0,18
37	Khawaja Buqhra Mosque	3825188	514295	-0,22	-0,37	0,42	-0,61	-0,85	0,06	-0,96	-0,14	30,82	139,22	19,88	0,15
38	3rd Khayerkhana Mosque	3825532	513548	0,18	0,03	0,48	-0,28	-0,53	0,11	-0,79	-0,05	6,21	107,28	19,60	0,81
40	School No. 12, Khayarhkana Mina	3825825	514010	0,15	0,00	0,66	-0,77	-1,01	0,14	-0,69	-0,40	8,12	61,93	15,12	0,46
41	Wazirabad Mosque Mesbah	3823746	515264	0,11	-0,04	0,55	-2,11	-2,36	0,36	-1,17	-2,20	1,67	22,34	19,60	0,45
42	Wazirabad 7 Street Kalay Fattulah	3823352	515541	0,22	0,06	0,80	-1,72	-1,97	0,52	-1,04	-1,78	2,80	40,55	33,04	0,43
44	Kalay Musa Qabr Gora	3822392	516023	0,13	-0,03	0,40	-1,74	-1,99	0,40	-1,15	-1,82	1,76	27,65	24,64	0,70
46	District No.5 Street-Kaema-e-Afshar	3820864	510362	0,24	0,09	0,47	-2,06	-2,31	0,27	-0,97	-2,07	2,23	14,96	18,48	1,01
47	District No.5 Secondary Girls Schools of Afshar	3820160	510527	0,31	0,16	0,47	-1,91	-2,16	0,13	-1,16	-2,18	1,32	20,35	31,36	1,49
49	District No.5 Tank-e-tele Dewan Begi	3819866	508917	0,40	0,24	0,47	-2,30	-2,55	-0,57	-1,26	-2,76	0,80	13,68	14,84	2,08
50	Kashal Khan High School	3817556	514570	-0,26	-0,41	-0,58	-1,49	-1,74	0,45	-1,82	-1,85	3,01	29,51	21,56	1,18
51	Aminy Secondary School Hyada Shams	3816698	514291	0,56	0,41	1,10	-1,93	-2,18	0,07	-0,86	-2,16	1,59	21,61		1,00
52	Bag Raes Chelsoton Street	3816152	519216	0,71	0,56	1,38	-1,92	-2,17	0,11	-0,72	-2,16	1,52	22,30		1,08
55	New Technikum New Technikum Street	3814598	514523	0,28	0,13	0,41	-1,78	-2,03	0,33	-1,19	-2,06	1,48	22,00	0,00	1,40
61	Darulaman Quala-e-Ali Mardan	3815399	510358	0,19	0,04	0,40	-1,79	-2,03	0,43	-1,18	-1,95	1,65	25,42	0,00	1,05
62	Hydary-mowck Quala-e-Ali Mardan	3814942	510498	0,34	0,19	0,73	-1,81	-2,05	0,29	-0,88	-1,83	1,79	24,43	40,88	0,90
63	Quala-e-Bakhtyar School	3814396	510514	0,14	-0,02	0,20	-1,92	-2,17	0,23	-1,16	-2,02	1,47	21,30	20,72	1,15
64	Siemens District Bibi Fatimatazzehra Mosque	3816599	512447	0,33	0,18	0,65	-1,60	-1,85	0,55	-1,04	-1,77	2,35	35,97	34,16	1,00
67	Haji Yaqub	3821768	515544	0,33	0,18	0,90	-1,79	-2,04	0,32	-0,98	-1,90	2,23	32,63	26,04	0,57
68	Share-Naw Shaheed Street	3821947	515677	0,34	0,19	0,84	-1,80	-2,05	0,27	-1,03	-1,98	1,83	28,99	0,00	0,70
71	Visastelle Deutsche Botschaft Goethe Institut	3820687	516104	0,27	0,12	0,63	-1,82	-2,07	0,11	-1,19	-2,09	1,77	26,06	22,96	0,85
72	Kalay Hazara Chendaul New Street od Chendaul	3818884	515521	0,21	0,06	0,25	-1,48	-1,72	0,82	-1,30	-1,79	2,10	37,15	22,12	1,53
73	Khoshal Khan, Quaiti Mosque Alef-Khoshal-Khan-Mena	3819818	510117	0,11	-0,04	-0,05	-2,14	-2,39	-0,26	-1,51	-2,56	1,13	14,74	15,68	1,87
74	Nahee-3, Charahi Shahid Debory Said Maqsod Shah Mosque	3818449	511637	0,37	0,22	0,37	-1,64	-1,88	-0,13	-1,35	-2,16	1,18	23,03	17,92	2,40
76	Wazir Akbar Khan 13 Street 344	3821921	516698	0,13	-0,02	0,48	-1,93	-2,18	0,34	-1,18	-2,04	1,82	29,06	26,32	0,60
77	Wazir Akbar Khan 13 Street 346	3821924	516713	0,12	-0,03	0,54	-1,87	-2,11	0,47	-1,17	-1,96	2,09	32,91	28,56	0,53
78	Ghazi Stadium	3819593	517835	0,25	0,10	0,67	-1,33	-1,58	0,40	-1,21	-1,59	2,85	32,77	28,28	0,71
79	Shah Shaheed 1st Street	3818947	518174	0,32	0,17	0,86	-1,59	-1,84	0,54	-1,07	-1,78	2,72	28,86	24,36	0,63
87	District 6 Dashti Barchi Road, Mosque Emani hasan Mujtaba	3818158	510117	0,41	0,26	1,04	-1,51	-1,76	0,55	-0,88	-1,61	2,28	32,89	12,88	0,58
88	District 7 Habibia High School	3817874	513604	0,14	-0,01	-0,04	-2,07	-2,31	-0,29	-1,55	-2,56	0,82	14,06	26,88	2,09
89	District 7 Masjet Khagamolah	3817625	513168	0,31	0,16	0,75	-1,66	-1,91	0,47	-1,02	-1,80	2,19	28,62	25,48	0,75
91	Karti-3 Abdul Ali Mostaghni High School	3817605	512714	0,30	0,15	0,64	-1,54	-1,78	0,58	-1,09	-1,73	2,92	32,99	26,60	0,90
92	Karti-3 Rukhshana Girls High School	3817494	512710	0,31	0,16	0,66	-1,58	-1,83	0,53	-1,08	-1,77	2,62	30,08	28,00	0,89
93	Karti-3 Road K, Marjet Jamboret	3818058	513143	0,31	0,16	0,74	-1,71	-1,96	0,40	-1,05	-1,87	2,42	26,70	22,68	0,77
95	Project Timany	3824012	514562	0,30	0,14	1,19	-1,64	-1,88	0,68	-0,80	-1,54	3,15	44,58	23,80	0,26
98	Wazir Arbat High School	3824193	514459	0,23	0,08	1,22	-1,37	-1,61	0,14	-0,90	-1,28	6,18	67,49	32,20	0,19
101	Project Timany 5th Street	3824849	514920	0,29	0,14	1,33	-0,58	-0,82	0,28	-0,71	-0,37	14,16	179,75	35,00	0,21
102	District No 5, Etfaio Saraki-Millie-Bus-Station	3820074	510457	0,13	-0,02	0,04	-1,91	-2,15	0,15	-1,42	-2,26	1,27	20,06	22,40	1,69
103	District No 5, Spin Kalai	3820247	510077	0,09	-0,06	-0,05	-2,07	-2,31	-0,10	-1,46	-2,42	1,19	17,53	18,48	1,74
104	District No 5, Spin Kalai Char-Raki-Maktabi	3820386	509744	0,15	-0,01	0,02	-2,19	-2,44	-0,28	-1,45	-2,60	1,04	14,16	14,56	1,86
105	District No 5, Kalai, Askar, Afshari-Silo	3820703	509792	0,12	-0,03	-0,03	-2,20	-2,45	-0,21	-1,44	-2,57	1,23	12,19	14,00	1,87
106	Burji-Barki, District No 5 Kismati-Alef-Khoshal-Mena	3820804	509606	0,38	0,23	0,74	-1,88	-2,13	0,06	-1,08	-2,14	1,38	21,20	0,00	1,03
107	Ministry of Irrigation Darluaman Road	3815036	511980	0,42	0,27	0,99	-1,62	-1,87	0,46	-0,96	-1,82	2,15	35,15	0,00	0,71
109	Shar-e-Naw Park Street, Park Cinema	3821454	515536	0,24	0,09	0,75	-1,80	-2,04	0,26	-1,04	-1,88	2,26	33,52	29,96	0,54
110	Sharara Sharara Hill	3821176	514504	0,06	-0,09	0,21	-1,82	-2,07	0,32	-1,14	-1,83	1,65	26,09	23,24	0,81
111	ISAF HQ Well 2	3820945	517759	0,20	0,05	0,56	-2,00	-2,24	-0,09	-1,22	-2,21	1,90	21,14	20,72	0,73
112	ISAF HQ Well 2 new	3821045	517481	0,26	0,11	0,70	-1,91	-2,16	-0,04	-1,17	-2,13	1,73	24,93	22,40	0,72
113	Bibimahro	3822147	517964	0,22	0,07	0,62	-1,31	-1,56	0,70	-1,16	-1,49	2,70	42,74	31,64	0,66
114	Quala-e-khyat egalate-Awal	3822986	518517	0,31	0,16	0,89	-1,78	-2,02	0,24	-1,04	-1,93	2,69	27,94	25,20	0,55
115	Air Port Do-saraka	3823721	519082	0,28	0,13	1,00	-1,88	-2,13	0,25	-0,95	-1,92	2,31	29,48	24,36	0,37
116	Kalay chaman bibimehro	3824193	518062	0,32	0,17	1,08	-1,58	-1,83	0,43	-0,94	-1,65	4,42	41,44	29,12	0,35
117	Kalay chaman bibimehro Khalta Kaka gailon	3824285	518000	0,31	0,16	1,09	-1,60	-1,85	0,50	-0,91	-1,63	3,90	41,00	29,40	0,34
118	Khuja Bughra Cental Base	3826869	516283	0,09	-0,05	0,39	-1,71	-1,95	0,05	-0,84	-1,42	3,34	12,68	9,80	0,72
119	Kodga Beghra Mosque	3826925	515076	0,09	-0,06	0,18	-1,47	-1,71	0,07	-1,05	-1,38	2,36	17,41	8,12	1,12
120	Chaman-hozory	3819053	517811	0,14	-0,01	0,48	-1,98	-2,23	0,09	-1,27	-2,21	1,76	20,29	22,12	0,60
121	Poli scharchi Short Wave Antennae Radio Afganistan	3821884	519655	0,18	0,03	0,75	-2,08	-2,33	0,04	-1,10	-2,17	1,53	27,14	24,08	0,40
122	Poli scharchi Customs Office	3822578	521748	0,42	0,27	1,55	-2,07	-2,31	0,36	-0,76	-2,04	4,57	29,55	32,76	0,21
123	Police Station 9	3822611	522307	0,39	0,24	1,32	-1,85	-2,10	0,41	-0,82	-1,86	3,34	34,88	29,68	0,30
124	Hood Khel	3822480	523760	0,37	0,22	1,31	-2,23	-2,47	0,00	-0,84	-2,24	3,07	24,88	27,72	0,27
125	Hood Khel	3822494	524405	0,42	0,27	1,52	-2,07	-2,32	0,19	-0,65	-1,94	3,79	28,19	27,16	0,22
126	Poktialot	3822418	526628	0,17	0,02	0,87	-1,97	-2,22	0,26	-1,09	-2,03	2,31	20,96	30,80	0,30
127	Middle School Military Academy	3822969	528124	0,01	-0,14	0,43	-1,10	-1,34	-0,02	-0,83	-0,72	19,77	42,29	14,28	0,43
128	Shohadai, Salehen Barkat Balta Hesar Shohada	3817983	517361	0,10	-0,05	0,05	-1,17	-1,41	0,49	-1,27	-1,33	1,87	46,79	9,80	1,54
129	Bigkcha Sayed Shohada Salehin	3817527	517227	0,05	-0,10	-0,03	-2,18	-2,42	0,11	-1,21	-2,23	0,82	14,42	10,36	1,46
130	Qualay Hashmat Khan	3817016	517584	0,17	0,02	0,42	-0,99	-1,23	0,40	-1,03	-0,98	6,30	58,30	24,64	0,89
131	Qualay Hashmat Khan	3816077	518221	0,11	-0,04	0,18	-1,38	-1,63	0,18	-1,19	-1,47	2,75	19,44	9,24	1,21
132	Qualay Hashmat Khan	3816174	518888	0,15	0,00	0,23	-1,82	-2,07	0,67	-1,13	-1,91	1,88	20,25	17,08	1,13
133	Bin Hesar	3815989	519917	0,25	0,10	0,61	-1,71	-1,96	0,35	-1,00	-1,76	2,90	23,49	24,64	0,79
134	Kart 4, Main Road	3818537	512645	0,26	0,11	0,17	-1,95	-2,19	-0,33	-1,42	-2,43	1,07	19,15	17,64	2,20
135	Karti 4, Near Police Station No.3	3818318	512815	0,23	0,08	0,37	-1,82	-2,06	0,05	-1,29	-2,14	1,63	20,21	18,48	1,22
136	Rabi Balchi Girls High School	3818586	513458	0,18	0,03	0,38	-2,08	-2,32	-0,24	-1,30	-2,36	1,35	18,17	17,36	0,99
137	Karti 4, Sarak Awal	3818370	513124	0,15	0,00	0,44	-1,37	-1,61	0,67	-1,21	-1,53	3,35	35,66	25,76	0,75
138	District 7, Hesa Daum Kyzargagh Demorad Khan Quala Shah Agssse	3817535	514049	0,28	0,13	0,59	-2,00	-2,25	-0,06	-1,24	-2,34	1,44	18,49	17,92	0,92
139	District 7 Mosque	3816389	513596	0,20	0,05	0,40	-2,14	-2,39	-0,22	-1,44	-2,59	1,39	17,46	15,68	0,96
140	Timani Project Street 5	3824355	514710	0,20	0,05	1,10	-1,24	-1,49	0,23	-0,90	-1,15	6,23	75,27	31,92	0,21
141	Khajabegra Mosque	3825268	515325	0,18	0,03	1,15	-0,90	-1,14	0,06	-0,61	-0,47	18,32	80,92	12,60	0,18
142	Khajabegra Midany Project	3825415	515776	0,10	-0,05	0,49	-0,58	-0,83	0,09	-1,08	-0,55	7,89	81,52	7,28	0,57
143	Khajabegra Sharic Danish	3825730	514293	0,04	-0,11	0,33	-0,64	-0,89	0,16	-0,75	-0,23	7,09	73,20	20,44	0,56
144	Golaye Khogaboghra	3826220	514254	-0,01	-0,16	0,24	-1,10	-1,35	0,10	-0,93	-0,82	5,20	39,81	13,72	0,56
145	Mosque of Kaja Abdullay Ansar	3826308	513475	0,07	-0,08	0,39	-1,11	-1,35	-0,02	-0,66	-0,64	4,93	63,76	47,04	0,58
146	Khair Khana, 3rd Part Danesh	3825920	513418	0,05	-0,10	0,37	-1,19	-1,44	0,21	-0,82	-0,87	4,78	46,36	31,08	0,53
147	Khair Khana, 2nd Part Cinema	3825943	513120	0,02	-0,13	0,29	-0,92	-1,17	0,09	-0,83	-0,57	4,61	56,18	26,32	0,58
148	Khair Khana Mariam High School	3826036	512751	0,04	-0,11	0,29	-0,94	-1,18	0,30	-0,87	-0,65	4,77	44,88	17,36	0,64
149	Khair Khana Bazaar Street	3826359	512465	-0,14	-0,29	-0,16	-1,31	-1,55	0,25	-1,12	-1,08	3,38	24,58	10,36	0,79
150	Khair Khana, 2nd Part Masjet Street	3826806	512312	0,01	-0,14	0,04	-1,46	-1,71	0,28	-1,15	-1,41	2,05	17,58	8,12	1,05

Appendix 11: Calculated hydrochemical parameters of the groundwater of the Kabul Basin 2004 (part 2).

Nr.	Location	x_long	y_lat	saturation index (SI)								SAR	Total Hardness	Carbonate Hardness	Ca/Mg
				calcite	aragonite	dolomite	gypsum	anhydrite	barite	strontianite	celestite				
151	Khair Khana, 2nd Part Aryana	3826893	512798	0,21	0,06	0,62	-1,72	-1,96	0,10	-0,67	-1,38	2,39	14,10	12,04	0,69
152	Kulola Poshta Kalai Jangi	3822046	514286	0,07	-0,08	0,47	-2,19	-2,44	0,08	-0,91	-1,97	1,71	16,34	17,36	0,50
153	Timany 6th Street	3822470	514738	0,33	0,18	1,05	-1,73	-1,97	0,58	-0,87	-1,72	2,94	44,27	38,08	0,42
154	Timany 9th Street	3822687	514465	0,01	-0,14	0,35	-2,13	-2,38	0,20	-1,28	-2,23	1,93	20,57	19,88	0,48
155	Timany 12th Street	3823158	513788	0,10	-0,05	0,76	-1,82	-2,06	0,26	-0,96	-1,69	2,72	32,35	23,80	0,28
156	Timany 13th Street	3822892	514174	0,15	0,00	0,86	-1,70	-1,95	0,30	-0,97	-1,63	3,54	42,96	31,08	0,29
157	Karti 4 Mosque Saidyl Morsalain	3822366	512085	0,08	-0,07	0,23	-1,63	-1,88	0,17	-1,07	-1,59	2,24	23,56	22,68	0,85
158	Karti 4 No.11, Middle Street	3822546	511914	0,13	-0,03	0,31	-1,59	-1,84	0,38	-1,02	-1,54	3,18	31,33	29,68	0,87
159	Karti 4 Dekepak Girls High School	3822556	511452	0,05	-0,10	-0,05	-2,01	-2,25	0,32	-1,39	-2,25	1,00	17,64	13,44	1,53
160	District 17 Nowabud Dekepak	3822978	511157	-0,36	-0,51	-0,93	-1,95	-2,20	0,33	-1,60	-1,99	1,25	17,53	13,44	1,67
161	District 17 90 Family	3823230	511557	0,09	-0,06	0,25	-2,06	-2,31	0,10	-1,04	-1,99	1,88	17,21	19,04	0,84
162	District 17 Tahee-e-Maskan	3823879	511355	0,06	-0,09	0,22	-2,09	-2,34	-0,02	-1,12	-2,06	1,62	11,75	11,76	0,86
163	Karti 4 Sharara, AchmadZai	3821209	514380	0,09	-0,06	0,21	-1,62	-1,86	0,49	-1,25	-1,76	2,31	33,11	26,60	0,98
164	Shar-e-Naw Char Rahi Ansari	3821244	515159	0,26	0,10	0,69	-1,89	-2,13	0,45	-1,08	-2,02	2,01	27,63	26,60	0,67
165	Shar-e-Naw Saroon Road	3821099	515400	0,27	0,12	0,72	-1,79	-2,04	0,52	-1,05	-1,91	2,49	36,56	36,40	0,68
166	Quolla Poshta Street 1	3821802	514413	0,35	0,20	0,92	-1,84	-2,09	0,43	-0,91	-1,91	1,96	29,01	27,72	0,63
167	Quolla Poshta Sharwali-Blak	3822263	513797	0,18	0,03	0,77	-1,89	-2,13	0,25	-0,85	-1,71	3,01	31,03	30,80	0,38
168	Quolla Poshta Hoza-e-Nahia-e-Char	3822980	512790	0,07	-0,08	0,72	-1,97	-2,22	0,23	-0,62	-1,47	7,33	20,61	29,40	0,25
169	Quolla Poshta Vegetable Market Street	3823508	512328	0,13	-0,02	0,82	-0,76	-1,01	0,55	-0,71	-0,41	11,45	74,87	23,52	0,28
170	Khair Khana Taymascan Masjet, Mulla Azam	3823901	511852	0,10	-0,05	0,49	-1,72	-1,97	0,17	-0,80	-1,43	2,70	24,15	21,84	0,54
171	Deekeepak Street 1	3824732	511453	0,05	-0,10	0,07	-1,62	-1,87	0,01	-1,08	-1,55	2,47	15,54	11,48	1,14
172	Rahman Mena 200 Family School	3816771	521354	0,21	0,06	0,95	-1,74	-1,98	0,52	-0,98	-1,72	2,53	32,99	23,52	0,29
173	Taymani Khyrul-bashar-Mosque-Street	3824859	513954	0,04	-0,11	0,94	0,07	-0,17	-0,19	-1,08	0,16	38,66	579,80	18,20	0,15
174	Khair Khana 3rd Street, Chel-metra	3824715	512916	0,04	-0,12	0,34	-0,90	-1,15	0,01	-0,99	-0,75	8,63	42,82	15,12	0,50
175	Khair Khana Imam-Reza-e-Ghareeb Mosque	3824659	511982	0,08	-0,07	0,25	-1,22	-1,47	0,23	-0,99	-1,10	3,30	32,45	17,64	0,83
176	Khair Khana Quala-e-Nagar	3825011	512032	0,07	-0,08	0,31	-1,10	-1,34	0,18	-0,85	-0,81	5,04	35,54	19,60	0,71
177	Khair Khana Market Street	3825458	512072	0,09	-0,06	0,31	-1,02	-1,26	0,16	-1,01	-0,92	3,85	45,08	21,84	0,80
178	Khair Khana 2nd Street	3825928	512316	0,15	0,00	0,56	-1,06	-1,30	0,18	-0,69	-0,70	3,82	41,25	19,04	0,59
179	Khair Khana Post Office	3825880	511660	0,04	-0,11	0,19	-1,39	-1,63	0,17	-1,03	-1,25	2,27	21,08	10,36	0,84
180	Khair Khana Quala-e-Hesae-Awal	3825529	511522	0,04	-0,11	0,13	-1,09	-1,34	0,12	-1,13	-1,05	2,98	30,10	17,08	0,94
181	Poll-e-Artal (District No 1) Sarak-e-chalstoon	3818750	514958	0,14	-0,01	0,13	-1,83	-2,09	0,14	-1,40	-2,19	1,40	19,70	17,92	1,35
182	Poll-e-Artal (District No 1) Jad-e-Maiwand Sarajee	3819188	517139	0,57	0,42	1,31	-1,56	-1,81	0,59	-0,88	-1,82	3,65	31,31	27,16	0,68
183	District No. 8 Ghalaya-e-Jadeed	3818062	518446	0,50	0,35	1,24	-1,66	-1,91	0,67	-0,73	-1,71	2,61	28,34	25,76	0,54
184	District No. 8 Ghalaya-e-Jadeed	3817417	519001	0,33	0,18	1,12	-1,81	-2,06	0,67	-0,80	-1,76	2,84	28,53	26,88	0,37
185	District No. 8 Ghalacha	3816719	519513	0,37	0,22	1,02	-1,86	-2,11	0,43	-0,87	-1,91	1,90	24,29	28,28	0,49
186	District No. 8 Ben-i-hesar	3815700	520079	0,20	0,05	0,86	-1,70	-1,94	0,53	-0,95	-1,64	2,95	29,11	27,72	0,37
187	District No. 8 Pull-e-Safeed Ben-e-hesar	3816501	519686	0,31	0,15	0,94	-1,79	-2,05	0,42	-0,90	-1,82	2,48	24,60	22,68	0,44
188	Rahman Mena 1st Street	3818624	520082	-0,17	-0,32	-0,03	-1,58	-1,83	0,19	-1,45	-1,67	2,95	25,40	21,28	0,50
189	Siha Sang New street of Kart-e-Naw	3818854	519672	-0,14	-0,29	0,01	-1,20	-1,45	0,02	-1,30	-1,14	3,01	45,25	17,92	0,56
190	Shah Shaheed 2nd Street	3818883	518585	-0,03	-0,18	0,15	-1,41	-1,65	0,54	-1,40	-1,57	2,86	38,60	32,48	0,67
191	Tymany Street 10	3822562	514021	0,17	0,02	0,69	-1,52	-1,77	0,26	-0,97	-1,47	3,08	39,58	29,12	0,45
192	Tymany Street 10	3822679	514302	0,08	-0,07	0,63	-1,65	-1,89	0,21	-1,06	-1,59	3,35	50,53	38,92	0,35
193	Tymany Street 10	3823057	514653	0,16	0,01	0,76	-2,02	-2,28	0,24	-1,02	-2,02	1,99	29,31	26,32	0,34
194	Old Station of Tymany Street 14	3823208	514313	0,12	-0,03	0,77	-1,88	-2,13	0,35	-1,07	-1,88	2,51	33,74	22,12	0,30
195	Sarak Wazirabad	3823395	514527	0,22	0,07	0,95	-2,09	-2,33	0,23	-0,99	-2,10	2,10	26,96	21,56	0,32
196	Sarak Wazirabad	3823638	514396	0,20	0,05	1,06	-1,59	-1,84	0,26	-0,94	-1,53	4,40	57,30	30,52	0,22
197	Tymany	3823659	514126	0,17	0,02	1,10	-1,54	-1,79	0,35	-0,88	-1,40	5,28	60,27	35,84	0,18
198	Tahia-e-Maskan	3823672	511578	0,02	-0,13	0,17	-1,89	-2,13	0,13	-1,20	-1,90	2,36	19,02	20,44	0,75
199	Kolola Pushta 2nd part od Parwan	3822498	512859	0,18	0,03	0,58	-1,71	-1,95	0,23	-0,79	-1,48	2,98	31,80	29,68	0,60
200	Kolola Pushta Shara-Ara	3822003	513837	0,08	-0,07	0,49	-1,79	-2,04	0,26	-0,99	-1,66	2,53	28,55	24,08	0,48
201	Tymany Pay Kobe Naswar	3823664	514813	0,03	-0,12	0,36	-2,00	-2,25	0,38	-1,33	-2,16	1,98	23,12	18,20	0,50
202	Tymany 2nd part	3823590	514183	0,03	-0,12	0,47	-2,04	-2,29	0,28	-1,15	-2,03	2,39	21,51	17,92	0,39
203	Quala-e-Fatullah 5th Street	3822927	515676	0,02	-0,13	0,27	-2,08	-2,32	0,24	-1,36	-2,26	1,69	21,23	19,04	0,61
204	Khair Khana Ariana	3826596	512688	-0,04	-0,19	0,05	-1,50	-1,75	0,27	-1,08	-1,33	2,87	17,63	9,24	0,79
205	Khair Khana Ariana	3826548	513056	-0,01	-0,16	0,19	-1,27	-1,52	0,07	-0,83	-0,89	3,97	23,89	9,80	0,65
206	Khair Khana Ariana	3826112	513134	0,00	-0,15	0,24	-0,85	-1,09	0,11	-0,94	-0,58	5,21	52,92	17,36	0,60
207	Khair Khana Cinema	3825640	512852	0,06	-0,10	0,45	-1,35	-1,59	-0,06	-0,68	-0,88	5,25	34,09	21,00	0,47
208	MMI	3819933	516670	0,24	0,09	0,50	-1,84	-2,08	0,11	-1,26	-2,14	1,95	24,32	22,96	0,95
209	MRRD	3820374	515969	0,17	0,02	0,38	-1,68	-1,92	0,30	-1,31	-1,95	2,01	29,92		0,94
210	Wazirabad Mosque M. Hanifa	3824083	515545	0,33	0,18	1,30	-1,55	-1,80	0,34	-0,86	-1,55	3,74	55,97	27,72	0,24
211	Ministry of Women Affairs	3821333	515885	0,23	0,08	0,68	-1,83	-2,07	0,18	-1,19	-2,03	1,77	29,64	26,04	0,66
212	Macroroyan Pool	3820884	518690	0,12	-0,04	0,42	-1,86	-2,10	0,12	-1,30	-2,08	1,94	23,91	20,16	0,64
213	Darwaza-e-Lahorri German Hospital	3819001	517740	0,10	-0,05	0,39	-1,81	-2,06	0,18	-1,38	-2,10	2,80	22,33	27,44	0,64
214	Amani School	3820858	516883	0,21	0,06	0,56	-1,94	-2,19	-0,01	-1,19	-2,14	1,67	23,49	21,28	0,75
215	Aishe-e-Durani School Pule-Baghe-Amani	3819546	516112	0,18	0,03	0,39	-1,85	-2,09	0,02	-1,32	-2,15	1,70	23,57	20,72	0,95
216	Khair Khana Seramina	3826875	513386	0,02	-0,13	0,04	-1,80	-2,04	0,05	-1,22	-1,82	1,73	12,04	8,96	1,14
217	Khair Khana 500 Families Project	3826982	513768	0,07	-0,08	0,34	-1,29	-1,52	0,30	-1,00	-1,12	2,37	25,12	8,12	0,73
218	Karti Parwan Mosque of Eman Azam	3821453	512734	0,17	0,02	0,23	-1,30	-1,55	0,93	-0,80	-1,07	2,51	44,55	29,68	1,34
219	Karti Sangi Tecdhing Training Said Jamaludin	3818853	512089	0,26	0,11	0,19	-1,97	-2,22	-0,36	-1,41	-2,45	1,13	17,79	17,08	2,12
220	Intersection Puli Surkh	3818084	512297	0,07	-0,08	-0,17	-2,02	-2,27	-0,17	-1,61	-2,50	1,25	14,35	15,12	2,01
221	Darullaman Allaudin Station Pump	3817116	512975	0,15	0,00	0,34	-1,82	-2,07	0,22	-1,25	-2,03	1,89	21,63	21,84	0,89
222	Darullaman Soviet Embassy	3816646	513212	0,14	-0,01	0,38	-1,92	-2,17	-0,07	-1,32	-2,19	1,41	22,29	19,88	0,70
223	Darullaman Elmufarhang Dekmazang	3818493	513973	0,19	0,04	0,54	-1,67	-1,92	0,42	-1,18	-1,85	2,36	27,84	23,24	0,70
224	Darullaman Fabrika Hajari & Najari	3818245	513764	0,28	0,13	0,77	-1,50	-1,74	0,57	-1,05	-1,62	2,94	34,91	28,28	0,63
225	Khashad Hkan Techer Training Academy	3820966	510374	-0,01	-0,16	-0,14	-2,21	-2,45	-0,03	-1,53	-2,54	3,20	9,93	16,52	1,35
226	Shar-e-Naw Embassy of Iran	3820913	516029	0,08	-0,07	0,25	-1,85	-2,09	0,12	-1,37	-2,09	1,79	25,79	23,52	0,83
227	Shar-e-Naw Jumhuriat Girls High School	3820425	515280	0,11	-0,04	0,46	-1,92	-2,17	0,26	-1,21	-2,04	1,90	30,43	27,16	0,60
228	Shash Darak Radio Afghanistan	3820894	517169	0,26	0,11	0,62	-1,83	-2,08	0,23	-1,07	-1,98	2,22	29,69	32,48	0,74
229	Wazir Akbar Khan BKA-House	3821902	516832	-0,01	-0,16	0,37	-1,86	-2,10	0,54	-1,27	-1,91	2,44	41,57	39,20	0,44
230	German Embassy	3821115	516431	0,18	0,03	0,50	-1,86	-2,11	0,10	-1,24	-2,08	1,70	26,93	26,04	0,74
231	Wazir Akbar Khan Mosque	3821543	516742	0,10	-0,05	0,44	-2,03	-2,28	-0,01	-1,25	-2,18	1,74	26,81	27,72	0,59
232	District 5, Khoshal Khan Mena	3820479	510785	0,12	-0,03	0,28	-1,84	-2,08	0,44	-1,08	-1,84	2,49	19,87	22,12	0,88
233	District 5 Fazil Big Afshar Well #9	3819744	506195	0,10	-0,05	-0,23	-2,25	-2,50	-0,99	-1,69	-2,84	0,51	13,41		2,77
234	District 5 Fazil Big Afshar Well #8	3819421	506371	0,18	0,03	-0,06	-2,20	-2,45	-0,67	-1,54	-2,73	0,60	13,24		2,58
235	District 13 Sharak Safa Afshar Well #5	3818351	506127	0,21	0,06	0,04	-2,16	-2,41	-0,51	-1,45	-2,62	0,71	14,23	15,12	2,29
236	District 5 Mogabete Sarai Heratee KPI Deep Well #2	3819532	510183	0,02	-0,13	-0,28	-2,23	-2,48	-0,55	-1,63	-2,69	0,90	13,83	14,56	2,10
237	Bagrame Village Logar Wellfield Well#3	3816295	525195	0,05	-0,10	0,51	-2,09	-2,34	0,16	-1,07	-2,02	2,10	18,99	19,32	0,38
238	Bagrame Village Logar Wellfield Well #10	3815477	525161	0,06	-0,09	0,69	-1,98	-2,23	0,42	-0,95	-1,81	2,73	25,31	24,92	0,26
500	Fazil Beg	67,07	34,51278	0,16	0,00	-0,12	-2,36	-2,61	-0,78	-1,56	-2,89	0,59	10,27		2,58

- Groundwater geochemistry of the Kabul basin -

Appendix 12: Hydrochemical analysis parameters of surface waters of the Kabul Basin 2005.

#	Sample name	x-coord.	y-coord.	type	location	pH	EC	K	Na	Cl	Mg	Ca	SO4	HCO3	NO3	Br	NH4	NO2	F	PO4	BO2	Ba	Li	SiO2	Sr	CO3	TIC	NPOC
							µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Kabul river - Camp Warehouse	529700	3822400	river	Kabul, near Qual e Shanan village, E Camp Warehouse	9,0	2200	9,6	248	263	137	39,7	312	453	4,7	0,78	0,02	-0,01	0,300	2,30	9,06	0,071	0,290	4,7	1,37	81,6	114	4,3
2	Kabul river - Artang bridge	515700	3819300	river	Kabul City at Artang bridge	7,7	919	7,1	62,7	69,5	48,6	66,9	61,8	386	27,7	0,13	-0,01	0,02	0,159	1,30	3,01	0,060	0,091	18,2	0,710		84,1	86,7
3	Paghman river - Darulaman	514100	3818000	river	Kabul, Darulaman	8,2	3000	55,3	344	248	53,3	101	na	1240	na	na	114	na	na	31,6	2,89	0,057	0,086	27,8	0,927		228	48,4
9	Paghman river -spring	nn	nn	spring	spring source	6,7	173	1,0	6,7	5,0	5,65	20,7	12,0	81	5,0	0,01	-0,01	-0,01	0,080	0,02	0,26	0,011	0,008	9,2	0,136		19,9	0,8
4	Logar river -Bagrame1	525500	3817000	river	NE inflow	8,6	1500	6,7	114	114	116	41,2	203	518	0,2	0,30	0,02	-0,01	0,195	0,24	5,61	0,057	0,273	14,4	1,05	27,6	116	3
7	Logar river -Bagrame2	525500	3817000	river	bridge at Bagrame	8,6	1470	6,8	117	119	119	39,6	207	519	0,6	0,31	0,09	0,28	0,224	0,22	5,87	0,054	0,269	14,1	0,982	24	114	2,6
5	Kharga Lake	503000	3824500	reservoir lake	bridge at Bagrame	7,1	162	1,4	5,0	3,2	4,38	22,5	9,0	81	4,9	0,01	0,01	0,08	0,099	0,02	0,17	0,022	0,002	9,1	0,141		17,8	1,9
8	Karez Amin	525400	3811100	karez (quanat)	Logar Valley, SE of Momozi	8,0	327	3,2	9,7	4,8	8,68	47,1	23,3	164	15,2	0,05	-0,01	-0,01	0,242	0,08	0,35	0,040	0,004	13,0	0,345		34,6	1

TIC = Total Inorganic Carbon, NPOC = non-purgeable organic carbon, na = not analysed, nn = not known

negative values: values below detection limits